The Asian Miracle and Modern Growth Theory*

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I. Accumulation and Assimilation Theories of the Asian Miracle

Over the past thirty-five years Korea, Taiwan,China, Singapore, and Hong Kong, have transformed themselves from technologically backwards and poor, to relatively modern and affluent economies. Each has experienced more than a four fold increase of per capita incomes. Each now has a significant collection of firms producing technologically complex products competing effectively against rival firms based in the United States, Japan, and Europe. The growth performance of these countries has vastly exceeded those of virtually all other economies that had comparable productivities and income levels in 1960. On these grounds alone the question of "how they did it" obviously is of enormous scientific and policy importance.

It has been less well noted that their growth has been historically unprecedented. The development of Japan in the half century after the Meiji restoration is widely regarded as comparable. However, Japan's per capita growth rate over this period was less than half that of the Asian nics since 1960. Of course, growth rates in general were slower during this earlier period. But the rate of catch up by the nics still is remarkable. It certainly would seem that there is an "Asian Miracle" that cries out for explanation.

Of course, economists have not been blind to or unattracted by the challenge. Over the last decade a number of different theories have been put forth purporting to explain the "Asian Miracle." (Amsden 1989, Kim and Lau 1994, Krugman 1994, Pack and Westphal 1986, Rodrik 1994, Westphal Kim and Dahlman 1985, World Bank 1993, Young 1993). There is unanimity among the different theories regarding the identity of some of the key causal factors. All of the Asian nics have experienced rapid growth of their physical capital stock. All have been marked by very high rates of investment in human capital. Virtually all theories about "how they did it" place these investments center stage in the explanation.

However, there are significant differences in the causal mechanisms stressed. At the risk of doing some violence to the actual diversity, for our purposes we find it useful to divide up theories of the Asian Miracle into two groups. One group, which we will call "accumulation" theories, stresses the role of these investments in moving these economies "along their production functions." The other group, which we will call "assimilation" theories, stresses the entrepreneurship, innovation and learning that these economies had to go through before they could master the new technologies they were adopting from the more advanced industrial nations; it sees investment in human and physical capital as a necessary, but far from sufficient, part of the assimilation process.

The "accumulation" theory has been pushed hard over the past few years by several economists, in a way clearly designed to strip away most of the "miraculous" from the Asian miracle. What lies behind rapid development is, simply, very high investment rates. Economists who take this point of view do not deny that adoption and mastering new technology and other modern practices was an important part of the story. Rather, the position is that one should try to explain as much as one can in terms of investments that enable movements along a production function, and see if anything much is left over, thus requiring explanation on other grounds. Several economists who have followed this path find that, according to their calculations, the lion's share of increased output per worker can be explained simply by increases in physical and human capital per worker. Thus there is little need to assign much of the credit for the growth "miracle" to entrepreneurship, innovation, or learning, except insofar as these are terms given to the shift to more capital and education intensive ways of production. (See e.g. Young 1993, Kim and Lau 1994, Krugman 1994).

To assimilation theorists, this point of view seems odd. The technologies that the nics came progressively to master during the 1970's and 1980's were ones with which, in 1960, they had no experience at all. To learn to use them effectively required the development of new sets of skills, new ways of organizing economic activity, and becoming familiar with and competent in new markets. To do this was far from a routine matter, but involved risk taking entrepreneurship as well as good management. (See e.g. Pack and Westphal 1986, Dahlman 1994, Amsden 1989.) What makes the Asian miracle miraculous is that these countries did these things so well, while other countries were much less successful. To be sure, adopting the technologies of the advanced countries required, among other things, high rates of investment in physical and human capital, and the nics achieved these high rates. But to say that these investments simply enabled these economies to "move along their production functions" seems a strange use of language. At the least, it poses the question of just what is meant by "moving along a production function."

Are we drawing a distinction without a real difference? We do not think so. The accumulation account stresses, simply, investments. The message is that other countries could have done as well as the successful nics if they had made the same investment effort. If the nation makes the investments, marshals the resources, development will follow. In contrast, the assimilation account stresses learning about, risking to operate, and coming to master, technologies and other practices that are new to the country, if not to the world. The "marshalling of inputs" is part of the story, but the emphasis is on innovation and learning, rather than on marshalling. Under this view, if when one marshals but does not innovate and learn, development does not follow.

A convinced accumulationist might respond by saying that, if one educates the people, and provides them with modern equipment to work with, they will learn. An assimilationist might respond that the Soviet Union, and the Eastern European communist economies, took exactly that point of view, made the investments, and didn't learn.[1] There is nothing automatic about the learning business. The response of the accumulationist might be that the old communist countries provided an economic environment where there was no incentive to learn to be efficient, either in a technological or an economic sense, much less to innovate. The assimilation theorist might agree, but then propose that it is important to understand, therefore, just how the successful nics did it. The accumulationist would reply that they got the prices right and made the necessary public investments. Economists who stress entrepreneurship, innovation, and learning would reply that it is not all that simple, and point to countries like Spain that have had high investment rates, and have got most of the prices right, but which are growing at far lower rates than the Asian nics.

The difference between the theories shows up strikingly in the way they treat the following four matters: what is involved in entrepreneurial decision making, the nature of technology, the economic capabilities lent by a well educated work force, and the role that exporting played in these countries' rapid development.

Accumulationists pay little explicit attention to firms, seeing their behavior as being basically determined by the environment - the incentives and constraints - they face, which determines the actions that are most profitable. Assimilation theorists, on the other hand, see entrepreneurial firms, and their ability to learn rapidly, as a critical factor behind the success of Korea and Taiwan,China, with their behavior supported by their environments, but only partially determined by external forces. (See e.g. Hobday 1995, and Kim forthcoming.) For an assimilation theorist, at least our brand, when firms

[1] Easterly and Fischer, 1995, stress the low ex post elasticity of substitution as an explanation of slow Soviet growth. This could also be interpreted as reflecting insufficient effort to identify and master new technology.

contemplate venturing on to ground that is new for them, the profitability of such venturing is highly uncertain, in the sense of Knight. Some firm managers will dare to venture; others will choose to stick close to the familiar. Thus, what firms do is determined by the daring of their decision makers, as well as by their environment. And whether an entrepreneurial effort will succeed or fail also is only partly determined by environmental factors. It depends, as well, on the zeal and smarts and learning abilities of firm management and workers.

Part of the difference here resides in how the different theories see technology. Accumulationists seem to believe that the state of technological knowledge at any time is largely codified in blueprints and associated documents and that, for a firm to adopt a technology that is new to it but not to the world, primarily involves getting access to those blueprints. In contrast, assimilationists argue that only a small portion of what one needs to know to employ a technology is codified in the form of blueprints; much of it is tacit and learning is as much by doing and using as by reading and studying. (See e.g. Nelson and Winter 1982, and Rosenberg 1994.) More, while many economists believe that technology is defined in terms of engineering and physical science, in fact the lines between the engineering aspects of technology, and the organizational aspects, are blurry, and controlling a technology often involves knowing how to manage a very complex division of labor as much as it involves knowing the relevant physics and chemistry.

Both of these differences show up in terms of how the two theories go about explaining the fact that the nics were able to increase greatly and rapidly their capital-labor ratios (by more than four fold over the thirty five years in question) without experiencing a significant decline in the rate of return to capital. The accumulationist is inclined to try to explain in terms of the technological alternatives that were available to firms in the nics. The ability to hold off diminishing returns is a reflection of the fact that the nics could draw on a very extensive frontier of technologies that already were in use in other countries. The richness of the frontier was manifest in the fact that the "elasticity of substitution" was high.

The assimlationist, on the other hand, would argue it is misleading and incomplete analytically, to try to specify a set of technological possibilities without considering the decision makers' ability to search and see and effectively take on board new technology. That is, what the accumulationist would explain in terms of the nature of the parameters of a conventionally defined production function, an assimilationist would explain in terms of skillful entrepreneurship and learning.

Along the same lines, the two theories also differ regarding how they see the effects of the rapidly rising education levels in these countries. For the accumulationist, rising human capital is treated simply as an increase in the quality or effectiveness of labor. Assimilationists, on the other hand, tend to see the effects of sharply rising educational attainments, in particular the creation by these countries of a growing cadre of reasonably well trained engineers and applied scientists, in ways similar to that sketched out many years ago by Nelson and Phelps, 1966. Well educated managers, engineers, and workers have a comparative advantage in seeing new opportunities and effectively learning new things. Thus the growing human capital of the nics was a very important support for successful entrepreneurship.

Note that the difference here mirrors the difference regarding how to interpret the high ex-post elasticity of substitution. The accumulationist sees both the ability to hold off diminishing returns to capital and the high economic returns to education in terms of the parameters of a conventionally defined production function. The assimilationist sees both as manifestations of the effective learning that was going on.

This same difference between the two theories also shows up sharply in how they treat the strong export performance of the nic manufacturing firms. The accumulationists tend to see the steep rise in manufacturing exports as just what one would expect in economies where the stocks of physical and human capital were rising rapidly, and shifting comparative advantage towards the sectors that employed these inputs intensively. From this perspective, there is nothing noteworthy about the surge of manufacturing exports, save that it is evidence that the economic policies of these countries let comparative advantage work its ways. In contrast, the assimilationists, while not denying that the nics were building a comparative advantage in various fields of manufacturing, tend to highlight the active efforts by government to induce, almost force, firms to try to export, and the entrepreneurship, innovation, and learning the firms had to do in order to compete effectively in world markets, even with government support.

Economists of the assimilation school have argued that exporting stimulated and supported strong learning in two ways (Westphal, Kim, and Dahlman, 1985, Pack and Westphal 1986). First, being forced to compete in world markets made the managers and engineers in the firms pay close attention to world standards. Second, much of the exporting involved contracting with American or Japanese firms who both demanded high performance and provided assistance to achieve it. The story here clearly is different than one which sees the development of these new competencies as, simply, the more or less automatic result of changing factor availabilities which called them into being.

We have noted that the assimilationist's position, at least the one we espouse, sees the high rates of investment by the nics in physical and human capital as a necessary, if not a sufficient, component of the assimilation process. These high rates themselves are remarkable, even if not miraculous. Under the argument of the assimilationists, these investments were at least partially induced by, and sustained by, the rapid innovation and learning that was going on.

Successful entrepreneurship in the nics certainly was facilitated by the growing supply of well trained technical people. On the other hand, it was not automatic that newly trained engineers would find work in entrepreneurial firms. There had to be entrepreneurial firms in which to work, or the opportunity to found new ones. Thus in the nics aggressive entrepreneurship supported and encouraged rapidly rising educational attainment, and served to make these investments economically productive. In contrast, in many other countries initially as poor as Korea and Taiwan,China, the market for college graduates was almost exclusively the Government bureaucracies, where their skills arguably made little contribution to economic development.

Successful production of new products almost always required that firms acquire new physical capital. There's no question that policies in these countries encouraged saving. But on the other hand, what made saving and investment profitable was the strong and effective innovative performance of the firms that were entering new lines of business.

We think it apparent that the two broad theories differ both in their causal structures, and in the hints they give about "how to do it." The emphasis of the accumulationists is on getting investment rates up and the prices right. The message of the assimilation theorists is that successful industrial development requires innovation and learning to master modern technologies; effective innovation and learning depend on investments, and a market environment that presses for efficient allocations, but it involves much more. And, indeed, to a considerable extent, the investments needed are induced by successful entrepreneurship.

Section II considers the argument that careful attention to the numbers and rigorous calculation supports the accumulationist theory, and there is little evidence that innovation and learning played much of a role. We argue that the commonly used calculations do not do what their proponents claim. In Section III, we propose a different way for discriminating between a change in output accompanied by changes in inputs that can be considered simply "a movement along the production function," and a change that seems to involve innovation and learning. In the light of the argument we develop there, in section IV we consider the evidence. We propose that that evidence strongly supports the assimilationist's case. Section V considers in what ways the differences between the two theories matter.

II. Why the Standard Calculations in Fact Don't Discriminate

The case put forward by its proponents for the accumulationist theory is based on calculations of two sorts. One is a growth accounting. The other involves fitting a dynamic production function. In both methods the strategy is, basically, to try to calculate the effect of input growth on output growth, holding the "production function" constant, and see (under growth accounting) if anything much is left over as a "residual," or (under production function fitting) whether the passage of time itself seems to contribute to output growth over and above what is explained by input growth over time. We argue here that, contrary to widespread views in economics, neither kind of calculation can separate out growth that "would have occurred without technical advance" from growth that involved technical advance.

It often is not recognized adequately that the simple logic of growth accounting is only applicable to the analysis of <u>small</u> changes in inputs and outputs. (See e.g. Nelson 1973.) The procedure basically involves making estimates of the marginal productivities (or output partial elasticities) of the various inputs that have changed and, in effect, using these to calculate the contribution of input expansion to output growth by using a first order Taylor series. However, in the case of the Asian tigers the investments whose contribution to growth is being estimated have been cumulatively very large. While repressed by the format of growth accounting, which usually sets up the calculations in terms of average yearly changes, and thus makes the changes <u>appear</u> relatively small, in the countries in question capital per worker increased more than four times over the past three decades, and years of average educational attainment also increased greatly.

The calculations in standard growth accounting take marginal productivities as estimated by factor prices (or output elasticities as estimated by factor shares) as exogenous. However, under the assumptions of neoclassical production function theory (which lie behind the growth accounting logic), large finite changes in inputs can lead to large finite changes in marginal productivities. Table 1 shows, for a CES production function, what happens to the share of capital, initially at .3, for different proportional increases in the capital-labor ratio, for different elasticities of substitution. Note that for small increases, capital's share does not change very much, regardless of the elasticity of substitution. For large changes, however, the elasticity of substitution makes a huge difference in terms of what happens to capital's share. For example, 300% increase in the capital labor ratio and an elasticity of substitution of .2 implies a decline in the capital share from .30 to .0017.

We know that, in the countries in question, despite the large changes in their quantities, the rates of return on physical capital and on education stayed high. Indeed, capital's share of output certainly didn't fall much and may have increased. We noted earlier that one explanation is that technologically determined elasticities of substitution, in the sense of standard production function theory, were quite high, and thus significant increases in these inputs relative to others had only a modest effect on marginal productivities as the economy moved along its ex-ante production function. Under this explanation a good share of output increase indeed would have occurred without any technical advance. This seems to be the implicit argument of the proponents of the accumulation theory. However, another explanation is that the elasticities of substitution, defined in the standard way, were quite low, and that only the rapid taking on board of new technologies prevented the sharp diminishing returns and falling partial output elasticities for the factors that increased most that one would have observed had these economies stayed on the production functions that existed at the start of the development traverse.

Consider the latter explanation, which we believe is the correct one. Under it, innovation and rapid learning are driving growth. However, a growth accounting of a standard sort might show a very small residual, or even a negative one. The factor shares of the more rapidly growing factors - physical and human capital - would be and would remain high, as a consequence of the rapid learning that made their continued expansion productive. Rapid factor accumulation was not an exogenous phenomenon but a response to high private profitability. A growth accounting might "attribute" the lion's share of output growth to input growth. There would be little left to explain in terms of innovation and learning, despite the fact that these are the basic factors driving growth.

The use by some scholars of the Tornqvist index for the weights applied to input increases represents acknowledgement that, if one is interested in the impact on output of finite changes of inputs along a production function, output elasticities can change along the way. But the use of such an index (as by Young, 1995) does not deal with the problem highlighted here. The index uses actual shares for each year throughout the period. But the actual shares at the end of the period can be, and in the case in question almost surely were, affected by the technological changes that occurred over the period. In general they are not what the shares would have been at the new input quantities had the production function stayed constant over the traverse. As shown in Table 1, the evolution of shares depend on the value of the elasticity of substitution and the magnitude of the increase in the capital-labor ratio. Also, while not shown in Table 1, they also depend on technical change itself. It is thus inappropriate to use the observed factor shares as weights since they assume something one is trying to estimate, namely, TFP growth.[2]

We want to underline this point because many economists seem to believe that the absence of a large residual in a growth accounting is strong evidence that the lion's share of growth was due to movements along a prevailing production function. This is just not so if the input changes involved are large. Growth accounting alone cannot tell whether the relevant elasticities of substitution were large or small, and thus cannot distinguish between the two

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[2] The following equations can be derived for the rate of change of factor shares for a general production function, Q = f(K, mL) in terms of the initial share of capital, α, the elasticity substitution, σ, and the rate of Harrod-neutral, labor augmenting technical change, m:

$$S_K^* = [(1-\alpha)(1-\sigma)/\sigma]\ (m - k^*) \qquad (1)$$

$$S_L^* = [\alpha)(1-\sigma)/\sigma]\ (k^* - m) \qquad (2)$$

Equations (1) and (2) show that the factor shares utilized in Tornqvist calculations will be affected by both technical change, in this case labor augmenting, and changes in capital-intensity. The impact will be smaller the greater σ and m. In estimating the Tornqvist index of inputs,

$$T = \Sigma_i\ [1/2\ (S_{i,t} - S_{i,t-1})\ (\ln x_{i,t} - \ln x_{i,t-1}), \qquad (3).$$

The $S_{i,t}$ are taken to be exogenous and, assuming competitive input markets, (3) measures the contribution of inputs x_i to output. T is then substracted from the log difference in output to obtain the desired measure of TFP growth. But the $S_{i,t}$ are not in fact exogenous but are themselves affected by technical change as shown in (1) and (2).

stories sketched above about the sources of growth. There is an "identification" problem.

One might think that the fitting of a dynamic production function can avoid this logical limitation of growth accounting, when input changes are large and finite. However, in practice the identification problem cannot be resolved this way.

The basic issue in question is how much of experienced growth of output per worker can be ascribed simply to the large experienced increases in physical and human capital per worker that were achieved over the period between 1960 and 1995, and without recourse to the argument that the production function "shifted". Let us focus on the growth of physical capital. Table 2 shows, for a CES production function, the increase in output per worker that would be generated for different increases in the capital-labor ratio, and for different values of the elasticity of substitution. As with our earlier analysis of what happens to capital's share, for large changes in the capital labor ratio, the elasticity of substitution matters, a lot.

Consider then the two "explanations," depicted in Figure I, for a large increase in output per worker, between time one and time two, associated with a large increase in capital per worker. In the explanation on the left hand side, in which the elasticity of substitution is assumed large, much of experienced labor productivity increase would have occurred even had the economy stayed on its production function of period one (the dotted curve). The way the production function is drawn depicts only weak diminishing returns to increasing capital intensity. The firm or economy in question is presumed to know, at time one, how to operate effectively at much higher capital intensities than were employed then, but chooses not to do so because prevailing factor prices made it more profitable to operate at low capital intensity. Between time one and time two, factor availabilities changed.

In contrast, in the explanation on the right hand side, experienced productivity growth is almost totally the result of the establishment of a new production function (the solid curve) in that very little productivity growth would have occurred had the economy remained on its old production function. Under this explanatory story, at time one the firm or economy in question knew very little about how to operate effectively at significantly higher capital intensities. (The elasticity of substitution that would have obtained if the firm had been limited to operating technologies it knew initially was very low.) To have increased capital per worker without learning about and learning to use new techniques would very quickly have led to low or zero marginal returns. Thus the economy, in order to deal productively with the changed factor price regime of period two, had to do a lot of "learning," or "innovating," and in fact it did.

Both explanations fit the data at time one and two. The "levels" and the "slopes" of the old production functions are the same at time one, and the levels and slopes of the new production functions are the same at time two. This point was highlighted by Diamond, McFadden, and Rodriguez (1971), and Nelson (1973), over twenty years ago. It seems to have been forgotten.

When one "fits" a dynamic production function statistically (through many not just two points and slopes), how does one discriminate between these two explanations? Obviously one needs to place some restrictions on the form fitted, for example, that the rate and direction of "technical advance" be constants over the period, or that the underlying production function always have a particular "kind of general shape." Most of the econometric exercises we are concerned with here have imposed relatively loose restrictions, although sufficient to enable a best fitting equation to be calculated. However, even if an equation that looks like the left hand side explanation wins the "maximum likelihood" contest (as in Kim and Lau, 1994), if the constraints on functional form are relatively loose it is a good bet that an equation that looks like the right hand side explanation is not very far behind. Standard regression techniques of the sort that have been employed do not enable confident acceptance of one explanation and rejection of the other.

The graphs drawn in Figure 1 are in fact regressions estimated from the actual data for Korea's manufacturing sector for the years 1962-91. The dynamic production function fitted to the data is a standard CES, with two inputs-capital and labor- and constant returns to scale. To keep the analysis simple and transparent we constrained technological advance to be neutral and constant over the period in question. The key parameters to be estimated are r, the rate of technological progress, and e, the elasticity of substitution.

In the left hand figure we forced e to be large, .9. Since growth of K/L then "explains" a lot of the growth of Q/L, the estimated rate of technological change, r, came out low, .016. For regression runs in which we set e as greater than one, the estimated rate of technological change was even smaller. In any case, once the analyst built in a term accounting for the effects of rising educational attainments, there would be little room for "technological advance" in the explanation for economic growth. In the right hand figure we constrained e to be low, .2. Since under this constraint the growth of K/L cannot "explain" much of the growth of Q/L, the estimated rate of technological progress, r, came out high, .045. While growing human capital can cut down on this figure, taking this factor into account is unlikely to make the rate of estimated technological progress trivial.

Both of these regressions, and one in which all parameters were chosen by least squares, yield values of R^2 of around .98, leaving little to choose among the regressions on a statistical basis. Again, we want to underline the point. The fact that the best fit of a dynamic function provides an explanation for growth in which technological advance plays a small role, and input growth accounts for the lion's share of growth, does not itself provide strong evidence against the argument that, in fact, growth would have been far less if there had not been significant technological advance. Only the imposition of particular constraints on the dynamic production function enables econometric technique to choose between the explanation on the left had side and the right hand side of Figure I. These constraints are basically arbitrary. And the imposition of somewhat different ones can change radically the estimated contribution of technical advance in the attribution.

The authors in question certainly have been careful with their data, and in the use of their methods. The problem is that the methods employed just don't do the job they are thought to do. Nor, at this stage of our argument, are we introducing "new data", although we agree that the issue is an empirical one. Before considering new evidence, it would seem important to do some rethinking of the kind of data that would discriminate between growth where entrepreneurship, innovation, and learning were central, and growth where they were not.

III. Back to Basics

How is one to decide between two different explanations, each broadly compatible with the macroeconomic data, when one stresses "movements along a production function" and the other emphasizes "entrepreneurship, innovation, and learning"? We propose that to get an empirical answer requires that one first ask some conceptual questions. What might one <u>mean</u> when one says that an observed change in inputs and outputs simply reflected a move along a production function? What might one <u>mean</u> if one argued it was not that simple, but that entrepreneurship and innovation in fact were involved? If we agreed on answers to these conceptual questions we might be able to agree on what kind of empirical evidence would be relevant.

Regarding what we economists seem to mean by "a move along the production function," reflect on the simple treatment in undergraduate microeconomics texts. The production function, there, is said to be the "efficiency frontier" of the "production set" - the set of all input-output combinations a firm can choose among. One way of explaining the set to students is to say that a firm "knows" a certain set of production techniques or activities, and the production set is generated by different levels and mixes of those activities that a firm might choose. In any case, the firm is viewed as both "knowing about" each of the alternatives, and "knowing how" to do whatever is associated with achieving the input-output vector associated with each.

The verbal articulation may admit that there might be modest "set-up" costs associated with marshalling and organizing to shift operations to a point within the set that is different from what the firm currently is doing, and that some adjustments (another form of set-up cost) might be required to get the new choice operating smoothly, although these shift costs are generally repressed in the formal modeling. However, it seems inconsistent with the "operating within the production set" idea if the set up costs for shifting to a new point involved doing a lot of exploratory "search and study" to identify and get a better feel for alternatives that, up to then, had been unfamiliar to the firm, and the "adjustment" involved a lot of trial-error-try again learning by doing and using. At least it would seem inconsistent if the results of searching and learning were highly uncertain, both to the firm ex ante, and to an economist trying to predict what the results would be.

Of course, a plausible interpretation of the production set idea might admit a certain amount of statistical uncertainty regarding inputs and outputs, particularly if there were unknowable outside forces, like the amount of rainfall, that bear on the process. But if the decision maker in question has only very rough ideas about the consequences of trying to do something, and initially about how to do it, that something does not seem to be an activity that can be regarded as within the unit's production choice set. The production set of a firm would appear to be limited at any time to those things the firm knows about and knows how to do, with good confidence and skill. Or at least that is how economists implicitly define the concept.

On the other hand, a move that involves a lot of study of initially hazy alternatives, or research and development where even the nature of the outcome is not clear in advance, would, according to these criteria, be regarded as a "technological" change or "innovation" for the firm in question. We do not see how such a move possibly can be regarded as one "along a prevailing production function," if economists adhere to what they teach about the meaning of choice sets.

We call attention to the fact that, under the way we are proposing the distinction be drawn, a firm's production set in principle could be very extensive. Indeed, much of what some versions of the new neoclassical growth theory treat as "technological advance" would, under the principles suggested here, be regarded as moves along a firm's prevailing production function. In these models (see e.g. Romer, 1990) investments in R & D are strictly up-front costs required to make a product or technique operational. But in these models (if not in fact) R & D is strictly a set up cost to make an activity the firm always knew about available for use. There are no Knightian uncertainties involved.

However, once we get away from particular abstract models, most e conomists who have studied the processes empirically understand that the introduction to the economy of products or processes significantly different from any employed before does not look like a move "along a prevailing production function." It is well documented empirically that, while theoretical engineering calculations at any time encompass a wide range of techniques not yet brought to practice, the bringing to practice of new technology invariably involves "up front" research and development costs, with Knightian uncertainties at least early in the process. (See e.g. Nelson and Winter, 1982, and Rosenberg, 1994). While R and D can resolve some of these uncertainties, there are uncertainties in the R and D process itself. Further, even after R and D, there almost always are "bugs" at the start of operation, and it usually takes some time before the operation is really got under control. In many cases the attempts at innovating prove unprofitable, and need to be abandoned, or radically revised.

Of course, in this paper we are dealing with the adoption of technologies that, while new to the firm or country, are not new to the world. The issue, then, is whether such changes in the behavior and performance of firms in the nics can meaningfully be explained as changed choices within largely unchanging choice sets.

The accumulationists clearly have in mind that, if a technology is in effective use in one country, there are ways that firms in other countries can use to take aboard that technology at relatively low cost, and without significant uncertainties regarding the outcome of their efforts. Quite often detailed descriptions are available. One can hire consultants who are familiar with the practices involved. In many cases one can get assistance from the firms who are operating the technology, although some license fees may be required.

The assimilationist, in contrast, is skeptical about easy "technology transfer". To be sure, for many of the technologies that the firms in the nics adopted there were available engineering texts and articles and the like. Blue prints and specific handbooks often could be obtained. There are lots of consultants for hire.

However, the assimilationist would stress that such a move invariably involves not only "up front" costs of identifying, learning about, and learning to master the technique in question, but also significant uncertainties. The range of options is hazy. Things often do not work out as expected. Consultants seldom can guarantee success. Inevitably there is a lot of learning by doing and using. The costs, and the uncertainties, are greater the farther the technique being adopted is from those the firm actually has employed. In many cases major changes in firm organization may be required. The firm may need to learn to sense new markets. Firms attempting these changes can and often do fail. Those that succeed do so because they successfully learn to do things they simply could not do before. That is, they succeed by expanding their production sets.

IV What Does the Evidence Indicate ?

We can return now to the question of what kind of evidence one would need to determine whether an observed change was within a prevailing capability or choice set, or required an expansion of the set of things the organizations in question knew how to do. The prior section argued that the standard data and techniques for deciding simply do not do the job. We propose here that the kind of evidence that can be most persuasive involves examination of process, not simply time paths of inputs and outputs, and that such data are to be found at a quite low level of aggregation.

However, we believe that, if one has the issues that divide the theories firmly in mind, aat least some relevant evidence can be gleaned from more aggregate statistical analysis. Thus we have proposed that, for an accumulationist, the relationship between a country’s growth of output per worker and its investments per worker is determined by the set of technological alternatives "out there", which define its available production function. There would seem to be a presumption that this production function is the same for all countries, or at least some argument is needed if one is to propose that it is not. On the other hand, for an assimilationist, the relationship is determined, to a considerable degree, by the skill of the firms in a nation in searching and learning, capabilities that certainly can differ widely across nations. For an accumulationist, any significant variation among countries from a fitted cross country "production function" is something of a bother, and a puzzle to be explained. But an assimilationist would expect to find considerable variation. Further, the assimilationist's argument regarding Korea and Taiwan,China would imply that these countries achieved a significantly greater increase in output per worker than most other countries with comparable initial conditions, and comparably high investment rates.

Much of the analysis of the performance of the Asian coun tries has emphasized the absolute performance of the countries themselves, particularly as measured by total factor productivity growth and factor accumulation. To derive measures of performance or to interpret such measures, strong assumptions, which we have questioned, are made about the production function. Another measure of performance which is eclectic rather than based on a specific production theoretic base is the estimation of cross country regressions of the type used by Barro, 1991, and Mankiw, Romer,and Weil, 1992,[3] which permit comparison of a given country's performance relative to other nations. To see whether the performance of the two countries of greatest interest, here Korea and Taiwan,China, is unusual, we employ the following estimated cross country regression equation to explain differences in international rates of growth of GDP per capita,[4]

$$GDPG = -.0046 - .0308RGDP60 + .0296P60 - .0526GPOP + .0639i \quad (1)$$

where GDPG is the growth rate of per capita GDP, RGDP60 is GDP relative to the U.S. in 1960, P60 is primary school enrollment in 1960 as a percentage of the

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[3] These regressions were developed to test whether the standard Solow-Swan neoclassical model can explain cross country performance better than endogenous growth models. However, these models do not invoke strong assumptions about technical change and factor market pricing that is necessary in estimating TFP growth within a country over time. For a useful evaluation of this literature see Crofts, 1991.

[4] This equation is found in Pack and Page (1994). For a review of much of the literature see Levine and Renelt, 1992.

relevant age group, GPOP is the growth rate of the population from 1960-85, and i is the average investent/GDP ratio in 1960-85. The variable i is a proxy measure for the rate of growth of the capital stock, $K^* = \Delta K/K = iGDP/K$. Even if there is substantial variation in initial capital-output ratios, GDP/K, differences in the value of i over 25 years will outweigh such dispersion and yield a good approximation to K^*.

Figure 2 graphs actual minus predicted GDP growth per capita against i for countries in our sample that had high investment rates, i > 20 percent. As can be seen there is an insignificant negative relation between i and actual minus predicted growth. But among the high investment countries, the Asian nics, and Korea and Taiwan,China in particular stand out as unusual performers, even after adjusting for the other variables on the right hand side of (1) including the potential benefits of being laggards. Table 3 shows the actual minus predicted growth rates of a number of countries with very high values of i. Compared with nations such as Greece, Portugal, and Spain, Korea and Taiwan, China have unusual performance. It is clear that high physical investment ratios and initial conditions that are thought to be conducive to growth are not sufficient, alone, to explain the Korean or Taiwanese cases.

There is a large literature which adds additional variables to those included in equation 1 including some measuring macroeconomic management, export orientation, and so on. While such variables are of interest, they do not provide information about the nature of the production performance or the basis of success of economies in absorbing large quantitities of factor inputs while others obtained low returns. Our contention is that a critical element was the technological efforts of firms in Korea and Taiwan,China which allowed them to successfully initiate new industries and absorb new equipment. While other countries with high I/GDP ratios could purchase machinery which gave them the potential to improve their productivity, this could only be successful when it was combined with domestic effort to absorb the new technology. Moreover, much of the successful absorption effort is not attributable to formal and measureable R & D but efforts of firms to learn about new opportunities, improve organization and inventory management, and undertake minor but cumulatively significant changes in the production process. While proxies for such activity could be introduced in cross country estimates, their construction is tenuous and would lead to false concreteness. [5]On the other hand, case studies which are considered later, despite the difficulty of generalization, are suggestive and provide important insights into the origins of the exceptional growth shown in Figure 2 and Table 3.

A major problem with highly aggregated economic data is that it masks the magnitude and even the nature of the allocational changes going on. Thus, earlier we noted that in the 1990's Korean and Taiwanese manufacturing firms were heavily engaged in producing products that in the 1960's they were not producing at all. This is strikingly illustrated by Table 4 for Taiwan,China. In particular, note Taiwan's production of electronic goods, which by the late 1980s were accounting for roughly 21 percent of Taiwanese manufacturing exports. In 1960 virtually no electronics goods were produced in Taiwan,China. In both Korea and Taiwan,China, a considerable amount of the knowledge came from OECD purchasers of exports (Westphal, Kim, Dahlman 1985, Hou and San, 1993). The transfer of such information to local firms by importers desiring lower cost, higher quality products is an important feature of Korean and Taiwanese experience. But as Hobday (1995), Kim (forthcoming), Pack and Westphal, (1997) and others report in their detailed firm histories, summarized below, this information was only the initial foundation upon which firms then built their technological capacity, first learning rudimentary processing, then improving their productivity in small ways, then engaging in innovations in process engineering and product design. While some of the foundations were acquired from importers, the structure was mainly constructed through intense efforts on the part of firms.

At a slightly higher level of aggregation the rapid sectoral transformation in both Korea and Taiwan,China is shown in Table 5. Labor intensive, technologically simple sectors such as food processing, textiles, and clothing experienced a relative decline while capital and technology intensive sectors such as chemicals, metal products, machinery, and electronics expanded. It is difficult to articulate what it would mean to say that capital and labor were allocated to these sectors and were routinely incorporated in an existing well understood production function. To the contrary, there was a widespread perception in both countries that the technological competence of firms initially was insufficient to undertake efficient expansion in the newer sectors. In a more

[5] For cautions, usually disregarded, about data reliability, see Heston and Summers, 1991.

formal way, the appendix sets out a model which describes a growth pattern in which “craft” firms with lower profitability decline in relative importance while “advanced” firms expand. The two sets of firms have different production parameters and the aggregate process of growth which mimics that of a neoclassical process cannot be described as a movement along an international production function.

Within such a world the allocation of activity within the manufacturing sector almost certainly would be associated with considerable turnover of firms, with firms going out of business in the declining sectors, and new firms entering the expanding fields. Such a change in the allocation of activity within the manufacturing sector almost certainly would be associated with considerable turnover of firms, with firms going out of business in the declining sectors, and new firms entering the expanding fields. And within the expanding areas one would expect to see a certain amount of turnover as some firms try and fail while others succeed. Unfortunately, we do not have the firm turnover data that is directly relevant to the phenomena we are characterizing.

However, there are data on the number of firms of different sizes in Korea and Taiwan,China for several years, and a summary of these data is presented in Table 6. The pattern is roughly what one would expect under the assimilationist's story. There has been a striking decline in the number of very small firms, most of which very likely were locked into old technologies and producing traditional products, and a sharp rise in the number of middle size or larger firms; we conjecture that a large share of these were new firms entering the new product fields or older firms that succeeded in taking on board modern technology. In the early 1970s the productivity of these larger firms was strikingly higher than that of the small firms that, according to the story we are proposing, they were replacing.

However, to get at the details of what was going on would seem to require studying individual firms. Only by studying firms can one see just what was involved when they came to master new technologies and learn what was needed to operate in new product fields. As noted above there have been a large number of detailed studies of Taiwanese and Korean manufacturing firms, tracing the sources of the firms' rapidly growing range of manufacturing competencies. While a skeptic may argue these are anecdotal, the evidence from several hundred firm interviews can be regarded as no less compelling than the imperfect aggregate data which are employed to argue that there was limited technical change.

For example, a typical description of the production processes in the Korean engineering industries in the mid to late 1970s is enlightening. As shown in Table 5, this sector grew enormously during the last three decades and became Korea’s largest single sector. Yet as late as 1977, its production processes were described as exceptionally backward not primarily in the type of equipment utilized but in the organization of production. The following observations were given by a group of engineers and economists describing Korean machine producing plants as of 1977, fifteen years after Korea's major effort at industrialization had begun.

> The common pattern was one of machine placement that is haphazard rather than allowing for an orderly flow of work. Floor space is very crowded and the operation of machining, fabrication of components, assembly of parts, are scattered in any place that happens to have available room. Too much time is spent finding work, or the next job, or material. In some cases the men have to find their own area in which to work, perhaps make up some form of fixtures of their own, or find the means to obtain levels or measurements to work from. The almost universal characteristic is one of congestion and a mixing of operations that frequently leads to deterioration of quality because of improper floor planning. There is no adequate provision for working space around the main machines and the aisleways that are normally used to carry the flow of work are completely congested with work-in process.[7]

Yet fifteen years later these plants were producing high quality machine tools for export. The deficiencies described were amenable to improvements through learning better practice and significant reorganization. While it is possible to make such learning tautologically equal to moving along an international production function, it was costly, the results uncertain, and it took place over many years, suggesting a much more complex phenomenon, not replicated in many other countries in which capital accumulation was rapid.

The firm histories provide details of a complex interactive process in which OECD importers furnished some knowledge of production engineering to facilitate production in low cost firms. As these firms improved their cost and quality structure, the importers provided specifications for new products which

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[7] The World Bank, 1979. While the production processs described could be interpreted as a cost minimizing response to the relative cost of labor and space, the engineers observed that the same amount of space could have been reorganized in order to achieve a much better flow.

the local firms manufactured as original equipment manufacturers (OEM). To maintain their contracts they were forced to constantly reduce cost through improving productivity. The OEM process thus provided a strong learning environment in which firms not able to continue to meet quality and cost specifications in short term opportunistic relationships could easily lose their markets. To quote from a case study of an internationally known Taiwanese computer peripherals supplier:

> Foreign buyers are an important source of technological enhancement. Their rigorous specifications are seen as a challenge for the firm to meet. Equipped with different viewpoints and accumulated experience, they criticize a lot and suggest other ways of doing things. Although they do not provide exact blue prints, their suggestions are invaluable in upgrading the technology level of the firm. Still, our own R & D is the most important source of technology. Without this capability, the firm would not be able to evaluate research proposals, technology contracts, licenses, or buyers' suggestions. (Pack, Wang, and Westphal, 1996)

Thus, while some knowledge was readily obtained from the rest of the world, as the accumulationists correctly argue, this view is a partial one. Rather the transfers provided the skeleton upon which the flesh of major industrial prowess was built. Firm histories suggest that when transfers did occur, they were followed by internal learning and innovative efforts. The R & D figures and patent statistics shown in Table 7 for Taiwan,China provide one measure of the large formal domestic research effort which built upon imported knowledge. Between 1981 and 1991 the number of patents granted to Taiwanese nationals quadrupled, being roughly equal to foreign patents in 1991. Similarly, formal R & D spending increased from .5 to 2 percent of GDP. Moreover, formal R & D is likely to constitute a minor part of domestic technological effort.

Amsden (1989) provides a history of a Korean textile firm's learning. It commenced production in 1963 and most of the additions to the plant occurred before 1977. The machinery was purchased from Belgium, England, Japan, and Germany and the firm received technical assistance from its suppliers. Labor productivity shown in Table 8 improved substantially between 1977 and 1986 with basically unchanged quantities of machinery in both spinning and weaving. Output per unit of equipment improved as well in spinning and was roughly constant in weaving. The firm employed a large group of textile engineers to achieve this improvement in productivity. Two observations based on the data in Table 8 are relevant for our purposes. First, there was a steady increase in output per unit of labor after the equipment was installed and this is explicitly attributable to the firm's effort to improve its performance. Second, the last row in the table shows the output per unit of input relative to international best practice in British plants. Twenty five years after its establishment and after a considerable period of learning, the firm was still not operating at international best practice, a result hardly consistent with the view that firms in the NICs moved along an international production function.

The second example, also provided by Amsden, concerns the Pohang Iron and Steel Company, generally known as POSCO. Although it initiated production with imported equipment and with considerable technical assistance from abroad, it too engaged in intensive internal effort to augment its productivity. It did not simply move instantaneously to international productivity levels.

> To improve the performance of each piece of equipment, POSCO provided training to its workers. ... Between 1968 and 1979 training courses of one form or another involved roughly 61,4000 workers. Approximately 4,200 people were trained outside the company, 1,513 overseas. In 1984 alone, 9,900 workers had received training, some 1,000 of them in computer applications. POSCO also runs technical training schools in the town of Pohang, and in 1984 established an engineering college that it hopes will evolve along the lines of MIT. (Amsden, 1989, pp. 305-306.

While the improved general level of education for the labor force was a precondition for such training to be productive, it is no guarantor of such effort by firms. Case studies in other countries of firms with relatively high levels of educated labor do not uncover such evidence of systematic training. [8]

For our purposes, one of the most interesting set of firm studies are those undertaken by Michael Hobday (1995) of Korean and Taiwanese electronics companies. Hobday describes in detail how these firms started out, usually producing quite simple products, and then progressively moved on to more complex ones. In most of the cases he studied, these new complex products first were made to order for their foreign customers who, in the early stages, provided detailed engineering instructions and assistance. Gradually, however, many of these companies came to be able to do their own design work. In a number of cases, recently they have moved on to sell under their own brand label. Throughout the history of these firms, one can see them actively working to learn to do the things they were doing better, and to be able to do more sophisticated

[8] See, for example, the detailed firm studies in India in Lall, 1987.

and profitable things. In the early stages, this learning involved reverse engineering. As the companies began to do their own design work, this engineering effort began to be counted as research and development. He summarizes 55 firm case studies in Hong Kong, Korea, Singapore and Taiwan,China as follows:

> East Asian latecomers did not leapfrog from one vintage of technology to another. On the contrary, the evidence shows that firms engaged in a painstaking and cumulative process of technological learning: a hard slog rather than a leapfrog. The route to advanced electronics and information technology was through a long difficult learning process, driven by the manufacture of electronics goods for export. (p. 1188).

Linsu Kim (forthcoming) provides a set of analyses of Korean firms, in several different industries, that show much the same phenomena as does Hobday's study. The firms started out using relatively unsophisticated technologies and learned, over the years, progressively to master more sophisticated ones. By the 1990s many of these firms were approaching the technological frontier. But the paths they took were not simple, and success never was guaranteed.

The story about the development of Korean and Taiwanese firms told by Amsden, Hobday, and Kim, is strikingly similar to that told by Odagiri and Goto (forthcoming) in their study of how Japanese industry learned about and learned to master the technologies of the West in the years between the Meiji restoration and the advent of World War II. They find that a major amount of searching, exploring, trying, failing, and learning was required before Japanese firms acquired proficiency in the western technologies they were adopting and adapting. The decisions of firm managers to get into the new ways involved major uncertainties. Odagiri and Goto stress their "entrepreneurial" nature, and the innovation and learning that were involved. Our argument is that Korean and Taiwanese firms went through much the same process, half a century later.

To return to our basic analytic argument, we do not think that the industrial development of Korea and Taiwan,China since the 1950's, or of Japan a half century earlier (see Saxonhouse, 1974) can be interpreted as "moving along production functions," at least if that term connotes changing choices within a largely unchanging choice set. On the other hand, if the kind of entrepreneurship, innovation, and learning on the part of firms revealed in the case studies is considered as perfectly consistent with the notion of "moving along a production function," we do not know what that concept would exclude, and hence it becomes meaningless.

V. Do the Differences Matter, and If So, How?

The differences between the two theories would appear to matter for two different reasons. The first is, simply, regarding how one understands what happened. What lies behind the Asian miracle? The second is that the two theories might imply somewhat different things regarding appropriate economic development policy. What kinds of government policies are helpful, and what are the lessons for other countries?

It is apparent that, for many economists, one of the strongest attractions of the accumulation theory is that it is clean and simple, and its basic outlines conform with the general theory about economic activity that ones finds in modern economic text books. It is at once delightfully iconoclastic, and comfortably conservative, to take the miraculous out of the Asian miracle by proposing that it all was a simple matter of moving along a production function. No appeal is needed to the idea of entrepreneurship or innovation, the sources of which might very well lie outside the effective province of neoclassical economics.

It also is clear that a major source of resistance to the assimilation theory is that it seems a complex theory which raises as many questions as it answers. This raises suspicions that the assimilation theory cannot be cleanly formulated. It is a comfort, therefore, that a simpler, more familiar theory seems capable of providing all the explanation that is needed.

And yet, what is at odds intellectually may be only a small part of the corpus of traditional economic theory. More, that particular part, which proposes that production sets can be sharply defined, and that there is a clear distinction between moving along the production function and having the production function shift, came into economics only a relatively short time ago. Perhaps these particular conceptions are not needed for most standard economic arguments, and maybe they have been accepted too uncritically in any case.

A strong argument can be made that the assimilationists' perspective is quite consistent with an older set of ideas in economics. The idea that economic growth can be explained by increases in the factors of production, and also by improvements in their productivity, goes back at least as far as John Stuart Mill. However, a striking feature of the earlier analyses of economic growth, as contrasted with the more contemporary treatments, is that there was no compulsion to separate sharply between the contributions of different sources of growth. For Adam Smith, increases in the size of the market, invention of better ways of performing a task, growing mechanization, and changing organization of work, all go together. They would seem to also do so in Mill. The early post World War II growth accountants, in particular Moses Abramowitz, also stressed the interaction of technological advance, growing physical capital intensity of production, increasing exploitation of scale economies, rising educational attainments, and changes in the organization of production, as factors behind experienced economic growth. The question of which of these factors should be interpreted as moving the economy along a production function and which should be regarded as shifting it seems not to have been of major concern to these authors.

In Section II we argued that standard techniques do not permit one to separate sharply between movements along and shifts in the production function. Now we would like to argue that the very notion that one can make such sharp splits, even in principle, may not be a useful theoretical premise.

In particular, we would like to argue that "innovation" in practice is a matter of degree, not kind, and that our growth theory ought to recognize this explicitly. For any firm or organization at any time, there are some activities that are under practiced control, some that are not at present but seem easy to learn, others harder, others presently impossible but perhaps with research and experimentation achievable over the long run. The problem with now standard production theory is that it does not recognize these continuities, but rather presumes a sharp cliff between the known and the unknown.

The case studies of firms, briefly discussed in Section IV, show them moving from the known, to the unknown, but cautiously, and drawing from the known as much as they can. Yesterday's unknown becomes today's known, and the firms venture further. An effective theory of what has been happening requires, we believe, abandonment of the notion that production sets at any time are sharply defined, and thus that there is a clear distinction between moving to another perceived point and innovation. Rather, there is a continuum.

If one explicitly recognizes that that distinction is in fact fuzzy, does not that mean one has a fuzzy theory? Not at all. One of the striking features of the various "evolutionary models" of economic growth that have been built over the last decade is that, within them, innovation is treated as a matter of degree, firms move step by step into the unknown, and in so doing seldom move very far from the known.

Abandoning the sharp distinction between moving along a production function and innovation clearly is a big step analytically. Such a step would involve placing learning and adaptation at center stage of the behavioral analysis, and letting go of analytic techniques and arguments that presume that "profit maximization" is something that managers actually are able to achieve, rather that something they strive for intelligently. Yet it is arguable that most of the important and useful propositions about the role of markets and competition depend on the latter not the former.

The notion that competition tends to force price down towards costs, and to stimulate reform or elimination of high cost producers, goes far back in economics. The argument does not depend on the existence of sharply defined production sets, or the achievement by firms of policies that actually maximize profits, given the full set of theoretical alternatives. It is intelligent striving that does the job. Similarly, the argument that a change in factor prices will induce behavior that economizes on the factor whose cost has risen does not require either sharply defined production functions or actual maximization, but only intelligent striving.

What are the policy implications of taking an assimilationist, or evolutionary, view on what happened in the Asian miracle? Are the policy prescriptions fundamentally different under an assimilationist theory than under an accumulationist theory? In many ways the policy prescriptions in fact are quite similar, although the reasons behind the arguments differ somewhat.

Both neoclassical and assimilationist theories put considerable weight on investments in human capital. By stressing the importance of innovation and learning, and the role of an educated work force in these processes, the assimilationist might push even harder on the education front than would a modern neoclassical economist.

No disagreement either on the importance of investment in physical capital. However the assimilationist would highlight the role of such investments as a vehicle for taking aboard more modern technologies, and stress that if capital formation is not linked to effective entrepreneurship, the returns to investment almost surely will diminish greatly after a point. On the other hand the assimilationist would point to effective entrepreneurship as a key vehicle for keeping investment rates of return high, and would put less emphasis on simply trying to lift up the savings rate.

Both theories stress the importance of exporting. However, here too the reasons for the emphasis are somewhat different. The assimilationist sees exporting as an extremely important vehicle for learning, as well as a way of exploiting evolving comparative advantage. Thus, the assimilation theorist might be even stronger on the importance of exporting, and willing to bias the incentive system to induce firms to try to export.

Both theories stress the essential role of private enterprise, profit incentives, and an environment that stimulates managers to make decisions that enhance economic development. A neoclassicalist would focus on getting the prices right and making necessary public infrastructure investments. The assimilationist would take a somewhat more complex view on both of these matters. In particular, an assimilationist might stress the role of government funding and organization in building up national scientific and technological infrastructure from which firms can draw assistance. But under both theories, it is the energy of private enterprise that is key, and under both there is deep skepticism about the value of detailed government planning.

Both neoclassical and evolutionary theorists stress the great importance of competition. However here too the reasons differ somewhat, with the proponent of evolutionary theory pushing competition especially in contexts where innovation is both important and risky. From this point of view, competition is valuable largely **because** choice sets are not clear or not clearly defined and it is highly valuable, therefore, to get a lot of things tried.

So, the policy differences between the theories may be significantly smaller than the conceptual or analytic differences. This should not be a surprise. Economists were stressing the importance of profit incentives, and competition, and the dangers of government planning, long before the idea of a sharply defined production set came into vogue. Indeed, one can find these basic arguments in Adam Smith's Wealth of Nations.

Appendix: A Simple Evolutionary Model

The model we offer here is totally devoid of substitution possibilities within a given technology. Rather, all development takes place through the shifting of resources from one technology, which we will call craft, to another, which we will call modern. That is, "assimilation" is what is driving development here. Yet the growth pattern it generates could be interpreted by a growth accountant or a fitter of dynamic production functions as indicating that "accumulation" was the basic story. Expansion of physical and educational capital per worker is an essential part of the process by which the economy incorporates modern technology into its productive structure. But, on the other hand, accumulation without assimilation yields no returns.

Within this model a basic constraint on the rate of assimilation is the effectiveness of entrepreneurship. There always are profits to be made by expanding the modern sector. The strength of entrepreneurship in responding to profit opportunities determines the rate at which this happens. This response can be encouraged by a favorable policy climate. Moroever, a strong entrepreneurial response may, if successful, generate still more latitude for the government to pursue additional desirable policies. We believe this interaction accurately depicts an essential ingredient of the "Asian Miracle". The rapid expansion of human capital, another essential ingredient in our view, also plays a central role in this model, being necessary for the rapid expansion of the modern sector.

The model does not contain a third ingredient that we consider central; the rapid learning that took place in a firm after modern technology was first adopted. The model assumes in effect that such learning took place instantly and was once and for all, while in fact the firms moved progressively into more and more complex technologies. Here we choose to keep the model simple and abstract from the cumulative nature of learning.

Assume that there are two different kinds of fixed proportions constant returns to scale technologies, which we will denote c for craft and m for modern. Capital per unit of output is the same in the two technologies but output per unit of labor is higher in the modern sector than the craft. So also, then, is capital per unit of labor. If factor prices in the two sectors were the same, unit costs using modern techniques would be lower than costs using craft technology. However, the modern sector requires "educated" labor while education is not necessary or productive in craft technology.

At the start of the development traverse almost all of capital and labor is in the craft sector. However we assume that there is a tiny amount in the modern sector which serves, in effect, to "seed" the development process. At any time output per input per unit of labor input in the economy or industry as a whole will be the weighted average of labor productivity in the two technologies, the weights being the proportion of labor employed by each of the technologies. Let a_c be output per unit of labor in craft technology and a_m = output per unit of labor in modern technology, with $a_c<a_m$. Then:

$$Q/L = a_m L_m/L + a_c L_c/L \qquad (1a)$$

$$Q/L = a_c + (a_m - a_c)L_m/L \qquad (1b)$$

As L_m/L grows over the development process, so does Q/L. Since capital per unit of output is the same in the two sectors, an increase in L_m/L is accompanied by a rise in K/L. Indeed, within this model Q/L and K/L grow at the same rate.

Within our model a shift in the proportions of capital in the two sectors drives development. We assume that the price of the product is the same whether it is produced by modern or craft technology, and is constant over time. The latter can be rationalized by presuming that the product is sold on world markets and hence is insensitive to the quantity produced within the particular economy in question. We also assume that the cost of capital is the same in the two sectors. This means that differences in labor cost is the only factor that affects the relative profitabilities of the two technologies. We could modify these assumptions, but making them enables us to tell a cleaner story.

Let w be the price of labor in the craft sector, and gw it s price in the modern sector, with g>1. Thus g (for graduation) reflects an education premium. We assume, however, that g never is so large as to completely offset the productivity advantages of modern technology.

If one uses a prime over a symbol to denote an inverse, then the difference between the two sectors in cost, and profit, per unit of output, and capital, can be written:

$$\Delta C = w(a`_c - ga`_m) \qquad (2)$$

The higher profitability of modern technology than craft provides incentive to shift resources from the latter to the former. Within this model the strength of the response is determined by the effectiveness of entrepreneurship, denoted by e.

$$d/dt(\log K_m/K_c) = ew(a`_c - ga`_m) \qquad (3)$$

$$d/dt(\log K_m/K) = ew(a`_c - ga`_m)(1 - K_m/K) \quad (4)$$

If w and g are constants, the time path of K_m/K (and Q_m/Q) will trace out a logistic function. L_m/L will be increasing as these variables grow, but lagging behind them. Of course in the limit they all approach one. If w increases as development proceeds but not g, the rate of expansion of the modern sector relative to the craft will be accelerated reflecting that, since modern technology saves on labor, an increased w increases its cost advantage. An increase in the education premium, g, over the development trajectory will diminish the cost advantage of modern technology. On the other hand a decline in g, say as educated labor becomes more plentiful, will enhance it.

We know from equations 1a and 1b that, as capital and labor shift to the modern sector, K/L and Q/L will increase. If the amount of educated labor is responsive to demand, human capital also will be increasing. An economist looking at aggregate data likely would conclude that growth of Q/L was caused by the growth of physical and human capital per worker (and indeed such growth of capital was required for growth) and would argue that growth basically was due to "movements along the (economy-wide) production function". This "explanation" would repress two things. First, the force driving growth was the progressive adoption of modern technology, a technology virtually absent in the economy before development began. And second, while the profitability of employing modern technology was motivating the shift, the rate at which the modern sector replaces the craft was being determined by the strength of entrepreneurship. On the other hand, the traditional analysis would be right about the rate of growth of human capital being an enabling factor.

Thus consider two economies with exactly the same initial conditions, facing exactly the same opportunities to adopt modern technology, and having the same input supply elasticities. In one the response to profit opportunities, e, is high, and in the other low. The expansion of the modern sector, the growth of physical capital intensity, increases in human capital, and the advance of labor productivity, all would be faster in the former than the latter. An economist, thinking in terms of production functions, would try to explain the differences in terms of different rates of "accumulation", but the key factor behind the scenes would be differences in the entrepreneurial resonse to profit opportunities.[9]

Behind the scenes in the model growth of human capital is a enabling element. Other things being equal, a high e (resulting in rapid growth of the modern sector) will cause a rapid increase in the demand for educated labor. If increased supply is not forthcoming at the prevailing premium for educated labor, under various ways of modeling the dynamics g will rise. This will slow down the rate of growth of the modern sector associated with a given e. On the other hand, a rapid expansion of the educated work force can be absorbed productively only if e is high.

Just as, within this model, a high e tends to draw forth expansion of human capital, a high e tends to generate high profits in the industry as a whole, and hence a source of the savings to finance the investment in the modern sector. Both effects are of course moderated by "supply side" variables. To keep this presentation simple we have not introduced these explicitly into this model.

Within this model, development is a process driven by a disequilibrium. The disequilibrium, and the rate at which it is eliminated, shows up in this model in the behavior of capital's share over the development traverse. Set the constant product price as the mumeraire. Then the share of capital in total income is:

$$S_k = (1 - wa`_c)Q_c/Q + (1 - gwa`_m)Q_m \backslash Q \quad (5a)$$

$$S_k = (1 - wa`_c) + w(a`_c - ga`_m)Q_m/Q \quad (5b)$$

The first term of 5b is capital's share in the craft sector. The second term is the amount by which capital's share in the modern sector exceeds it's share in the craft, times the relative size of the modern sector.

Let b be the common capital output ratio in the two sectors, and r the equilibrium rate of return on capital. Assume that at the start of the development traverse the craft sector is in equilibrium. Then while capital's share in the modern sector is greater than br, since Q_m/Q is very small the share of total capital in the total industry is close to br at the start of the

[9] A considerable literature attests to these differences among developing countries. Contrast, for example, Lall's (1987) description of the behavior of Indian firms with those of Hobday (1996) and Kim (forthcoming) of the efforts of Korean and Taiwanese firms. Some of the observed differences may be attributable to differing policy environments.

traverse. We also assume that as development proceeds and the modern sector grows relative to the craft, wg grows to squeeze out excess profits in the modern sector. At the end of the development traverse, then, capital's share again is rb`. However in between, during the course of development, capital's share will exceed rb`. While the details depend on the exact specification, under plausible assumptions capital's share will take an inverted U shaped path over the development trajectory. As development proceeds and the modern sector expands, capital's share first will rise since quasi rents per unit of capital are higher in the modern sector than the craft, and a growing share of capital in that sector will more than offset the fact that rising wages will press down on rents per unit of capital in both sectors. Later, as the modern sector comes to be most of the economy, rising wages will diminish capital's share.

If one notes equation 2, one can see that the expression before $Q_m \backslash Q$ in equation 5b is proportional to the rate at which capital is being shifted from the craft to the modern sector, and hence the rate at which output per worker and capital per worker are growing. Thus capital's share will be high when capital and output are growing most rapidly. A growth accountant would naturally assign a good share of the credit for growth of output to growth of capital. If the supply of educated labor just keeps pace with the growth of employment in the modern sector, human capital also will be growing most rapidly when output is growing fast.

The foregoing captures the spirit of our argument in the text that, in the Asian Miracle, both large investments in human capital and forceful entrepreneurship which resulted in a growing modern sector and diminishing craft sector (Table 6) were key ingredients, and that they complemented each other strongly. Absent the ability and inclination to greatly expand human capital, aggressive entrepreneurship would have been stymied. Absent aggressive entrepreneurship, the returns to investment in human capital would have been low. And when both of these elements were present, together they made for high and rising profits in the modern sector which provided the finance for the large investments in physical capital that were necessary for rapid assimilation.

Figure 1

Alternate Interpretations of Growth

Figure 2

Table 1

Effect of Changes in Capital per Unit of Labor on Share of Capital in Output With Different Elasticities of Substitution

elasticity of substitution	10% Increase in Capital per unit of labor	100% Increase in Capital per unit of labor	200% Increase in Capital per unit of labor	300% Increase in Capital per unit of labor
	Share of Capital in Output (initial share = .30)			
.2	.2264	.0261	.0053	.0017
.9	.2978	.2841	.2750	.2687
1.0	.3000	.3000	.3000	.3000
2.0	.3101	.3774	.4260	.4615

Note: Tables 1 and 2 are derived in the following manner. Assume a CES production function $Q = A(\delta K^{-\rho} + (1-\delta)L^{-\rho})^{-1/\rho}$. From this we can obtain the following relationship between Q/L, K/L, and SK, the share of capital, in periods 1 and 2 respectively:

$$\frac{(Q/L)_1}{(Q/L)_2} = \frac{\delta(L/K)^{\rho} + (1-\delta)}{\delta(L/K)^{\rho} + (1-\delta)}$$

as well as the share of capital, SK in the two periods as:

$$\frac{SK_1}{SK_2} = \frac{\delta + (1-\delta)(K_0/L_0)^{\rho}}{\delta + (1-\delta)(K_1/L_1)^{\rho}}$$

The constant elasticity of substitution production function is undefined for $\rho=0$. In the calculations, the Cobb-Douglas is used when the elasticity of subsitution is unity. For the calculations in Tables 1 and 2, we define units so that $(K/L)_0 = 1$. Then $SK_0 = .3$ implies that $\delta = .3$.

Table 2

Effect of Changes in Capital per Unit of Labor on Output per Unit of Labor With Different Elasticities of Substitution

elasticity of substitution	10% Increase in Capital per unit of labor	100% Increase in Capital per unit of labor	200% Increase in Capital per unit of labor	300% Increase in Capital per unit of labor
	Percentage change in output per unit of labor			
.2	2.5	8.6	9.2	9.3
.9	2.9	22.4	37.1	48.3
1.0	2.9	23.1	23.1	51.6
2.0	2.9	26.4	26.4	69.0

Table 3

Investment Ratios and Predicted Minus

Actual Growth Rates

Country	Investment/GDP 1960-85	Actual minus predicted Growth Rate of GDP per Capita
Korea	24.3	.024
Taiwan, China	26.5	.042
Algeria	25.7	.008
Spain	26.5	-.001
Greece	26.3	.008
Ireland	26.4	.007
Panama	25.0	.002
Portugal	23.7	-.002
Poland	36.8	-.019

Table 4

Changes in Physical Production Levels
Selected Industrial Products
Taiwan (China) 1960-1990

Product	1960	1990
Man Made Fibers - millons of tons	1,762	1,785,731
Polyvinyl Chloride - millons of tons	3,418	920,954
Steel Bars - millions of tons	200,528	11,071,9991
Machine Tools	0	755,597
Sewing Machines	61,817	2,514,727
Electric Fans	203,843	15,217,438
Television Sets	0	3,703,000
Motorcycles	0	1,055,297
Telephones	0	1,055,297
Radios	0	5,892,881
Tape Recorders	0	8,124,253
Electronic Calculators	0	44,843,192
Integrated Circuits (1000)	0	2,676,865
Electronic Watches	0	5,115,695
Shipbuilding (tons)	27,051	1,211,607

Source: Taiwan Statistical Data Book, 1992, Council for Economic Planning and Development, Republic of China, Taipei, Table 5-6c.

Table 5

Share of Current Price Value Added Within Manufacturing

Sector	Korea 1963	Korea 1973	Korea 1988	Taiwan (China) 1966	Taiwan (China) 1986
Food, bev.	.34	.18	.11	.29	.11
textiles, cloth.	.22	.22	.15	.15	.16
wood, furn.	.04	.05	.02	.04	.03
paper, printing	.06	.04	.04	.05	.04
chemicals, petro.	.11	.20	.17	.21	.23
non. met. min.	.04	.05	.04	.07	.03
steel, iron	.04	.08	.07	.03	.06
metal prod, machinery, electronics	.12	.16	.36	.10	.18
other.	.02	.02	.02	.06	.13

Sources: Korea, United Nations Industrial Development Organization, <u>Handbook of Industrial Statistics,</u> various years, Taiwan (China), Directorate General of Accounting, Budget, and Statistics, <u>The Report on Industrial and Commercial Census of Taiwan -Fukien Area, The Republic of China</u>, various years.

Table 6

Percentage Distribution of Employment by Firm Size

	Number of Employees					
	4-9	10-19	20-49	50-99	100-499	500+
Taiwan, China						
1954	18	13	14	9	16	31
1961	18	10	14	8	17	34
1971	8	7	11	9	29	37
Index of Value Added Per Worker, 1971	NA	100	91	100	117	259
Korea						
1958	17	16	21	13	21	12
1963	15	14	16	12	21	22
1975	4	5	8	9	30	44
Index of Value Added Per Worker, 1971	NA	100	133	193	256	304

Source: Ho, 1980, Tables 3.1, D2, D3.

Note: NA, not available

Table 7

R & D and Patenting Activity in Taiwan (China)

Year	R&D/GDP	Total Patents	Taiwan (China) Nationals' Patents	Foreign Patents
1981	.95a	6,265	2,897	3,368
1986	.98	10,526	5,800	4,726
1991	1.65b	27,281	13,555	13,726

Notes. a, 1984; b, 1990.

Source: Taiwan Statistical Data Book, 1992. Table 6.7, 6.8

Table 8

Learning in a Korean Textile Factory

Year	1977	1986	1986 international best practice
Labor Productivity			
kilograms per manhour, ring spinning	52.4	78.5	156.25
kilograms per manhour, open end spinning[a]	137.1	210.3	324.30
meters per manhour, weaving	216.2	224.1	360.36
Machine Productivity			
kilograms per spindle, ring spinning	.20	.23	.21
kilograms per rotor, open end spinning[a]	.91	1.26	1.11
meters per loom, weaving	36.1	35.4	39.8

Note: a , initial year is 1979.

Source: Columns 1 and 2 adapted from Amsden, 1989, Table 10.4 Column 3 calculated from column 2 plus coefficients from Pack, 1987, Tables 3.1 and 3.2 and calculations underlying those tables.

References

Abramovitz, Moses. "Catching Up, Forging Ahead, and Falling Behind," Journal of Economic History, June 1986, 46:2, pp. 385-406.

Abramovitz, Moses, Thinking About Growth, Cambridge, Cambridge University Press, 1989.

Amsden, Alice, 1989, Asia's Next: South Korea and Late Industrialization, Oxford University Press, New York, 1989.

Barro, Robert, 1991, "Economic Growth in a Cross Section of Countries", Quarterly Journal of Economics, 1991, 105: 407-443.

Crafts, Nicholas, 1996, “Post-Neoclassical Endogenous Growth Theory: What are Its Policy Implications?,” Oxford Review of Economic Policy 12:30-47.

Dahlman, Carl. "Technology Strategy in East Asian Developing Economies," Manuscript, July 1994.

Diamond, Peter; MacFadden, Daniel; and Rodriguez, Michel. "Identification of the Elasticity of Substitution and the Bias of Technical Change: in MacFadden, Daniel (ed.), An Econometric Approach to Production Theory, North Holland, Amsterdam, 1972.

Ho, Samuel 1980, "Small-Scale Enterprises in Korea and Taiwan," World Bank Staff Working Paper No. 384, The World Bank, Washington D.C.

Hou, Chi-Ming and Gee San, 1993, "National Systems Supporting Technical Advance in Industry: the Case of Taiwan," in Richard R. Nelson, ed., National Innovation Systems, New York, Oxford University Press.

Hobday, Michael, Innovation in East Asia: The Challenge to Japan, London, Edward Elgar, 1995.

Kim, J.I., and Lau, L.J. "The Sources of Economic Growth in the East Asian Newly Industrialized Countries," Journal of Japanese and International Economics, 1994, pp. 235-271.

Kim, Linsu, forthcoming, From Imitation to Innovation: Dynamics of Korea's Technological Learning, Boston, Harvard Business School Press.

Krugman, Paul. "The Myth of Asia's Miracle," Foreign Affairs, December 1994, pp. 62-78.

Lall, Sanjaya, 1987, Learning to Industrialize, London, Macmillan.

Mankiw, G., D. Romer, and D. Weil, 1991, "A Contribution to the Empirics of Economic Growth, Quarterly Journal of Economics, CVI.

Nelson, Richard R.. "A Diffusion Model of International Productivity Differences in Manufacturing Industry," 1968, American Economic Review 58:1219-48.

------"Recent Evolutionary Theories About Economic Change," Journal of Economic Literature, March 1995, pp. 48-90.

------- and Winter, Sidney, An Evolutionary Theory of Economic Change, Harvard University Press, Cambridge, 1982.

--------. "Recent Exercises in Growth Accounting: New Understanding or Dead End?", American Economic Review, 1973, 73:462-468.

--------, and Phelps, Edmund. "Investment in Humans, Technological Diffusion, and Economic Growth," American Economic Review, May, 1966, 56, pp. 69-75.

Odagiri, Hiroyuki, and Goto, Akira. Technology and Economic Development in Japan, Oxford University Press, forthcoming.

Pack, Howard, 1987, Productivity, Technology, and Industrial Development, Oxford University Press, New York.

------, 1988, "Trade and Industrialization," in H.B. Chenery and T.N. Srinivasan, eds., Handbook of Development Economics, North Holland, Amsterdam.

----------, and Larry E. Westphal, 1986, "Industrial Strategy and Technological Change: theory vs reality," Journal of Development Economics, 22:87-128.

......, and John M. Page, "Accumulation, Exports and Growth in the High Performing Asian Countries," Carnegie-Rochester Papers on Public Policy, 1994.

......, Fang Ye Wang, and Larry E. Westphal, 1997, "Exports and Learning in Taiwan," ms., processed.

Rodrik, Dani, 1995, "Getting Interventions Right: How South Korea and Taiwan Grew Rich," Economic Policy

Romer, Paul. "Endogenous Technological Change," Journal of Political Economy, 1990, pp. 71-192.

Rosenberg, Nathan, "Uncertainty and Technological Advance," Manuscript, 1994.

Saxonhouse, Gary, "A Tale of Japanese Technological Diffusion in the Meiji Period," Journal of Economic History, March 1974, pp. 149-165.

Westphal, Larry E. ; Kim, Linsu; and Carl Dahlman. 1985, "Reflections on Korea's Acquisition of Technological Capability," in Nathan Rosenberg and Claudio Frischtak, eds., International Technology Transfer, Praeger, New York.

World Bank. The East Asian Miracle: Economic Growth and Public Policy, Oxford University Press, Oxford, 1993.

Young, Alwyn, 1995, "The Tyranny of Numbers: Confronting the Statistical Realities of the East Asian Growth Experience," Quarterly Journal of Economics, 110:641-80