The Progressive Division and Specialization of Industries

By Edward Ames and Nathan Rosenberg

I. INTRODUCTION

The title of this paper is an expression used by Allyn Young,[1] who asserts that potential economies from investment ". . . are segregated and achieved by the operations of specialized under-takings which, taken together, constitute a new industry". This segregation process is one of the most notable aspects of industrialization, but one about which rather little has been added in a systematic way since Adam Smith; even he, despite the renown of his remarks, devoted a total of four pages to the specialization of labor. We hope, by using a little formal reasoning, to rescue specialization from its current undeserved neglect. Since a major aspect of economic development is, in fact, embodied in changing patterns of specialization, we hope also to suggest some promising lines for the further study of the development process.

To illustrate the type of problem we are interested in, we offer a simple set of historical facts, which have no simple theoretical explanation. Until the 1820's there was no machine tool industry in either Great Britain or the United States. Machine tools were certainly used, but they were made by the firms which intended to use them. About this time, the machine shops of factories began to separate from the parent plants and become independent firms. Around 1860 there were many such firms, and they tended to produce a wide variety of tools. During the last part of the century, however, there was a strong tendency for these firms to reduce the variety of their output, so that while the assortment of tools made in either

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country grew, the variety produced per firm declined.[2] In the twentieth century, by contrast, there has been an opposite tendency. The number of firms has not increased with output, and may even have declined, whereas the number of kinds of tool produced per firm has increased. There is no theoretical economic explanation of why either the nineteenth century changes or the opposite twentieth century changes might have occurred.

In contrast to consumer goods industries where mass production techniques prevail, the capital goods industries possess certain unique features. The great bulk of their output consists of construction and machinery and equipment produced to conform to an exacting set of specifications laid down by the buyer of the capital good. As a result of this market constraint, the capital goods industries are characterized by (1) a large number of firms, (2) small average size of firms, (3) a highly heterogeneous output and (4) small production batches. Economies of scale are not very conspicuous while problems of product-mix and process-mix are obviously very important.[3] We argue that these features amount to a situation with which economic theory cannot now cope. These industries are very important ones, so the gap in our theory is not to be overlooked.

It is natural to conjecture that in some sense the firm optimizes the number of items in its catalogue, as well as its level of output of each item. The number of items, however, is discrete, being a whole number, and does not yield to the charms of the calculus. Thus conventional maximization theory does not help. It is useful to formulate the problem in terms of firms with joint production, if only because such a formulation makes it clear how complicated the theory of specialization is when viewed in this context.

II. THE ANALYTICAL FRAMEWORK

Consider a firm producing two outputs, and using for the purpose a certain collection of inputs, which have given prices. Denote by $(x_1, x_2|N)$ a situation in which outputs are x_1, x_2, and inputs are some given set of quantities, N. This situation is efficient, in the sense that the firm cannot produce more of one output, given N, without producing less of the other.

Let $S(N)$ denote the set $\{(x_1, x_2|N)\}$ of all combinations of output which can be produced with the given set N of inputs. Let us assume that there are pairs $(\bar{x}_1, \underline{x}_2)$ and $(\underline{x}_1, \bar{x}_2)$ having the property that for any element of $S(N)$, say $(x_1', x_2'|N)$, $x_1' \leq \bar{x}_1$, $x_2' \leq \bar{x}_2$; also that

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$x_1 \geq 0$, $x_2 \geq 0$. These pairs correspond to "specialization in output 1," and "specialization in output 2," respectively. (Such specialization may not imply that only one product is made; it means that as much of that product as possible is made for any collection of inputs.)

Now consider sets of output which are "between" these two. That is, consider pairs of the form $(\alpha \underline{x}_1 + (1 - \alpha)\bar{x}_1, (1 - \alpha)\underline{x}_2 + \alpha\bar{x}_2)$, and denote these by $(x_1(\alpha), x_2(\alpha))$. We inquire whether these are in $S(N)$. Under proper continuity conditions there will certainly be an element of $S(N)$ of the form $(x_1(\alpha), x_2'|N)$, and another of the form $(x_1', x_2(\alpha)|N)$. However, the minimum cost of producing $(x_1(\alpha), x_2(\alpha))$ may well be more or less than the cost associated with N, even though the cost of the pairs $(x_1(0), x_2(0))$ and $(x_1(1), x_2(1))$ is exactly N, by assumption.

Denote by $N(\alpha)$ the minimum cost of producing each particular combination $(x_1(\alpha), x_2(\alpha))$. From the foregoing construction, $N(0) = N(1) = N$, but if $\alpha \neq 0, 1$, $N(\alpha)$ is presumably not N. A tendency to specialize will exist if $N(\alpha) \leq N$ for values of α in some neighbourhood of 0 or 1 and $N(\alpha) > N$ for intermediate values of α; a tendency to diversify will exist if the inequalities are reversed.

This result was obtained by starting from a given set of quantities of a given collection of inputs with given prices. If a different set of quantities had been used, a different pair of bounds $(\bar{x}_1', \underline{x}_2')$ and $(\underline{x}_1', \bar{x}_2')$ would have been obtained; and if input prices had been different, $N(\alpha)$ would have had different values. Meaningful statements about specialization and diversification can be made in this context only if the properties of $N(\alpha)$ in the preceding paragraph turn out to depend only on α, and not on the actual amounts of inputs used, or the prices of inputs, at least for significant ranges of variation for both these collections of variables.

Assertions about specialization, in this context, are assertions that firms will select extreme values $\alpha = 0$ or $\alpha = 1$ in preference to non-extremal values; or that firms will shun these extremal values. The most general production function is one in which quantities of all the goods made in the economy appear as outputs of each firm, and the firm selects some convex combination $(\Sigma \alpha_i \bar{x}_i)$ of these. It is a familiar fact, of course, that for most firms almost all the α_i will equal zero, since most firms produce none at all of most of the kinds of goods used in the economy. It is also a familiar fact that there is a considerable amount of invariance in the list of goods (and even the proportions) produced by individual firms over moderately long periods of time. It therefore seems natural to investigate the question

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of specialization more directly, rather than as a limiting case of the difficult problem in joint output just formulated.

A theory of specialization, moreover, would have uses beyond those outlined. In the foregoing analysis, the set $((x_1, x_2|N))$ may be renamed, so that x_1 and x_2 represent quantities of inputs 1 and 2, and N represents a given bill of output. It is then possible to formulate another problem relating to the specialized use of inputs as compared to the combined use of both, given a particular output N. Manifestly individual firms use a relatively small proportion of the total number of inputs used in the economy.

Rather than consider specialization as a series of limiting cases in the theory of joint production functions, it is natural to approach the problem directly, and to try to see what can be said about the number of outputs or inputs used by firms. Such statements can be directly verified by reference to historical data. Indeed a variety of relevant generalizations have been proposed by economic historians. Some of these may even be relevant outside the context in which they were advanced: although originally formulated about countries which have succeeded in industrializing, they may be useful in outlining feasible courses for countries which are only beginning to industrialize.

We have found it possible to make some headway in the theory of specialization using the definitions given by Leibenstein.[4] He, in turn, is obviously influenced by Stigler.[5]

"1. A *commodity* is the entity that is the object of the production process, and has a specific set of attributes or specifications.

2. A *factor* is an entity, units of which can be purchased on the market, that has the capacity to carry out one or more activities.

3. An *activity* is our primitive concept. It refers to those necessary acts carried out by a factor, or functions of a factor, necessary in the productive process. We define a set of related activities as an *operation*.

4. A *process* is a specific set of operations necessary to produce the commodity in question. There may be a number of possible alternative processes.

5. By a *firm*, we refer to the entity that purchases factors, creates commodities, and sells commodities."[6]

An activity we associate with a command, "If X *do* Y." On an assembly line, the activity may reduce to "If a gizmo appears, fasten

a grommet to it." The associated operation may be sequential: "Drill a hole, insert a rod, fasten the grommet". Or the operation may be branching: "If the hole is less than two inches deep, return the gizmo; if it is two inches deep, pass the gizmo; if it is more than two inches deep, discard the gizmo." The activity, we say, is what is done by a particular agent, in the course of a process. The agent may be a man, or an entire firm The process yields a commodity.

Since men and machines are not stationed in a 1–1 proportion in an industrial process, the "length" of the process depends upon whether it is defined in terms of men or of machines. This fact turns out to be crucial when we consider specialization.

The specification of activities is not unique. From this fact stems a major operational difficulty. If I go to a craftsman and tell him "Make me a watch", I have apparently given a single order. If I must prepare the job specification for an assembly line producing watches (or if I make a time-and-motion study of the craftsman) I define a more complex sequence of commands. Indeed, a large part of the process of substituting machinery for labor is based on the precise specification of the sequence of commands. But one aspect of this process is the substitution of the command (to labor) "Tend this machine" for the commands "do $x_1, x_2, \ldots x_n$". For machines, the commands (specifications) grow longer. The "simple machine" executes the command "Do x". The more complicated machines execute the command "Do $x_1, x_2, \ldots x_n$".

It is convenient to define *specialization* at this point. It is clear that "complete specialization" by X means that X does one activity, and in general the more things X does, the less X specializes. It is also clear that the more things X does, the more skillful X is (the more skills he has).[7] Here X is an individual (man, machine, firm). When X, however, is a group, specialization is an average. We shall define the *skill* of a group as the average number of activities its members perform; and we shall take the reciprocal of this number as an index of specialization.[8]

Specialization is a ratio; it has a number of units of doers in its numerator, and a number of activities performed in its denominator. In this general form, we shall distinguish several types.

The term "vertical" is used here to mean "with reference to a particular process".[9] A process may involve several firms, as in the case of making finished metal goods from ores. It may be associated with the sequence of activities conducted by a single firm. *Vertical specialization* by a firm will refer to a tendency for a firm to carry

on a single activity in a process involving many firms. Vertical specialization by a factor will refer to a tendency for that factor to carry out a single activity within the productive process of a firm.

Horizontal specialization will refer to a collection of markets, which may be considered as a unit. Here a collection of sellers sell a variety of kinds of commodities (services) to a variety of kinds of buyers. The amount of horizontal specialization will be the average number of kinds of buyers to whom the average sellers sells.

We start our discussion with vertical specialization, that is, with a single assembly-line type of operation. Suppose that production may be described in terms of successive appearances of the object on an assembly line. The object, say, passes through n different states in the course of the process. That is, the production process involves the sequence State 1—Activity 1—State 2—Activity 2 . . Activity $(n-1)$—State n. We view two sets of inputs, called capital and labor, and consider specialization in terms of this sequence.

In the *Wealth of Nations*, the extreme of specialization contemplates associating with the i'th activity one worker and one machine. In the total absence of division of labor, there will be n activities per worker; and no machines are used. This definition is not very satisfactory. An increased specialization of labor increases average productivity of labor and also total output, whence follows the theorem "The division of labor is limited by the extent of the market." Since an increase in specialization is equivalent to a shift in supply (marginal cost) schedules, the cost of a marginal increase in specialization should equal the marginal revenue from the additional output. Suppose (marginal) divisions of labor classified on the basis of decreasing marginal product, that is increasing marginal cost, and there will be an optimal division of labor. Increased division of labor, in Smith, is associated with the increased possibility of introducing machines. A machine does rapidly what a pair of hands does slowly. Furthermore, the probability of invention increases, the more specialized the pair of hands. Therefore, the more specialized is labor, the greater the expected future rate of technological change This change alters the market equilibrium associated with an optimal division of labor.

This statement, more sophisticated technically than Smith's, seems to summarize the literature on vertical specialization. It fails,[10] however, to consider the fact that labor and machines have different degrees of specialization with respect to any one process, such that the more specialized the one, the less specialized the other.

Imagine a portion of the production process representable in the following scheme. In this section

Activity i	Activity $i + 1$	Activity $i + 2$
State i State $i + 1$	State $i + 2$	State $i + 3$
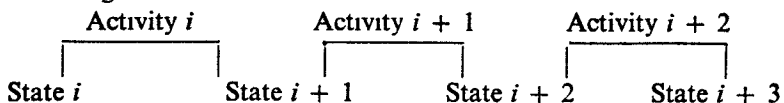
of the process, the object on the assembly line starts in state i, and after three activities ends in state $i + 3$. Imagine a skilled worker who performs all three activities. Each activity involves the use of one machine. For simplicity, we suppose that each machine has two lights. When the green light is on, the worker pulls a green lever, admitting one object into the machine. When the object is processed, a red light flashes on and the worker pulls a red lever, which drops the processed article into the hopper of the next machine.[11] This we will call Technology A. Next suppose this worker replaced by three workers, each of whom performs one operation using one machine. This we call Technology B. It corresponds to "division of labor" as Smith spoke of it (in the classic pin factory example). Finally, we suppose a third situation, Technology C. Here the three machines have been combined into one, tended by a single worker. As before, he has two lights to watch and two levers to pull.

In Technologies A and B each machine performs one activity. In Technologies B and C, each worker performs one activity. In Technology A, however, one worker performs three activities, and in Technology C one machine performs three activities. Thus the following tabulation of specialization may be made:

Technology	Labor Specialization	Machine Specialization
A	1/3	1
B	1	1
C	1	1/3

Manifestly these three situations are different; vertical specialization is a phenomenon in all cases, but the specialization of labor and of machinery vary in different ways from one case to the next.

One aspect of technological change has indeed been that described by Adam Smith. It is this aspect which Marx and Engels gloomily remark make the workmen "an appendage of the machine, and it is only the most simple, most monotonous, and most easily acquired knack, that is required of him." In contemporary jargon, man becomes "the cheapest non-linear servomechanism." It corresponds to the change from A to B, above.[12]

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Even if specialization had increased as much as Smith and Marx suggest, it would not necessarily involve making people into "appendages of the machine". If increased specialization is accompanied by increased training, then the more specialized societies may also be the most educated. Certainly the U.S. experience[13] suggests that the importance of training rises as industrialization advances. In particular, as we will suggest below, "maintenance" workers (who are typically highly trained) increase in importance relative to "production" workers. Moreover, professional and technical personnel grow rapidly in their relative importance, as do clerical and kindred personnel. Thus higher training may more than offset the deleterious effects, if any, of more specialization.[14]

The history of technology deals extensively with what we would call the skill and the training of machines. One aspect of technological change is exemplified by the change from B to C in our scheme. Here the individual machine becomes more skilled (less specialized) by taking on more activities in the assembly line. This is not the same thing, of course, as the increased "training of machines". The history of servomechanisms discusses the way in which machines have gradually become able to make more decisions. And just as an increase in the "education" of labor can result in increased productivity, given a set of machines, so also an increase in the "education" of machines increases their powers of discriminating, resulting in lower cost, for a given set of workers.[15] If more highly trained machines require more highly trained workers, Marx is wrong in saying that increased specialization of labor means reduced training for workers, and consequently their gradual economic and moral deterioration. In fact, greater specialization of labor is offset by greater training.

In the process of technological change, however, the sequence of activities may become irrelevant to the structure of jobs associated with labor and machines. Thus the automatic telephone exchange performs the same functions as the operator of a manual switchboard. However, division of labor has not meant the division of jobs into types corresponding to the individual steps performed by the operator; responding to an outgoing call, recording the address of the call, ascertaining whether the line is busy, etc. These steps are all performed within the machine. A variety of workers' jobs is associated with the machine, but these are not organized in terms of this sequence of steps. The assembly-line metaphor is inadequate, since a single job involves tending the machine with respect to some-

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thing which influences all stages of the completion of telephone calls.[16]

These two changes in specialization described, respectively, by the classical economists and the technological historians, appear to become non-operational concepts where machines become so skilled that the job functions of workers no longer are arranged according to the sequence of activities in the process. This situation with respect to labor is an analog of the situation with respect to tools which existed before the Industrial Revolution. Then, labor tended to be highly skilled, so that a single worker was associated with an entire process. Tools, however, consisted of hammers, forges, files, saws, etc.; their function was specialized, but it could not be identified with any single position along an assembly-line process, any more than a worker tending an automatic switchboard is associated solely with busy-signals. In effect then, twentieth century technology contrasts with earlier technology in this respect; formerly the sequence of activities was associated with a single skilled worker, and tools were specialized, though not ordered with the activities of the worker; today the sequence of activities is associated with a single machine, and workers are specialized, though not ordered with the activities of the machine.[17] Adam Smith's case of division of labor is a special one: workers and machines can be put into a sequence of pairs of which the production line is an example.

The hypothesis advanced above is a sort of statistical generalization about changes in the vertical specialization of inputs within a firm: technological change, on the average, increases the (vertical) specialization of labor and decreases the (vertical) specialization of machinery.

The citation which gives a title to this paper refers to another, and equally interesting proposition. Young observes that "Notable as has been the increase in the complexity of the apparatus of living, as shown by the increase in the variety of goods offered in the consumers' markets, the increase in the diversification of intermediate products and of industries manufacturing special products or groups of products has gone even further."[18] That is, technological change leads to decreases in the number of activities performed by the average firm located along an industrial process. It therefore may increase the number of firms. The firm specializes (vertically) and the number of interfirm transactions required to produce a unit of goods for final consumption increases.[19]

Propositions relating to vertical specialization of this sort are

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frequently related to propositions about the specialization of input factors. In a pre-industrial society of unspecialized labor and specialized machines, the boundary between firms in a process was apt to be the boundary between kinds of labor. Stigler cites Allen[20] to the effect that in the 18th century the locks, stocks, and barrels (to name only a few parts) of guns were all made by individual craftsmen, and "gunsmiths" merely ordered the finished parts and had them assembled by special sub-assembly "firms".

Conversely, in contemporary industry, labor is specialized and machines unspecialized, so that the boundaries between firms in a process are apt to be at the boundaries between the activities of different machines. This principle does not explain why steel mills own their own iron mines, but it may explain why pig iron, steel conversion and rolling all take place within a single firm.[21] As it became possible to handle hot metal in large quantities, steel conversion and rolling became the function of a single "machine."[22]

But production processes are not simply linear. They branch. In any linear production process, different inputs converge (as on an assembly line) to make an output. But it is also true that if this process is viewed at any particular stage, it may diverge. Thus some coal goes to steel mills, other coal to other users. Some iron is converted into steel, some is not. Some steel is rolled, some is cast; some rolled steel is used for automobiles, other rolled steel is not, and so on.

It is sometimes argued[23] that technological change means decreased vertical specialization of equipment (technological interrelatedness); a firm cannot sell intermediate products because these have only a momentary existence within a multi-activity machine If the final product of the firm cannot profitably be sold because of a price change, the firm cannot retain a share in a market for the intermediate product. A firm with more specialized equipment would be able to sell such intermediate output. Hence, if industrialization (and technological change) means increased skill (less specialization) of machines, it makes the "more advanced" firms less able to react to price changes, since they cannot salvage a part of their equipment for use in selling intermediate products.

For example, Italy and Flanders, Hicks has suggested,[24] regressed from an industrial to a pre-industrial condition in the 16th and 17th centuries, because their textile industries were displaced by foreign competition, and they could use their manufacturing facilities for no other purpose. In contrast, American metal-working plants shifted from guns to sewing-machines to bicycles to motor-cycles and

finally to automobiles in the half-century before the first world war.[25] This contrast results from the difference in "flexibility" in the use of machines. Italian and Flemish industry could make only textiles (or semi-finished textiles). American industry could use its plant to make a succession of quite different commodities.

Perhaps an even more pertinent case concerns the American producers of textile *machinery* who demonstrated great versatility in adapting their output to changing demand requirements throughout the 19th century. The resourcefulness and ingenuity of the textile machinery producers in fact played a major role not only in the mechanization of textiles but in the application of techniques of "machinofacture" to other industries, including machine tools, locomotives, firearms and agricultural machinery.[26] The contrast between the fate of the handloom weavers and the producers of the machinery which eventually displaced them is, we think, highly instructive.

Ceteris paribus, the closer firms are to the final product stage, the greater their vulnerability to shifts in consumer demand for specific commodities.[27] Resources at "higher order" stages of production, by contrast, are engaged in producing intermediate products which are eventually employed as inputs in a very large number of final products. A striking feature of nineteenth century industry is the extent to which resources and facilities devoted to machine production and metal processing more generally became skilled in the production of intermediate products which could be used throughout the economy. They came to possess a pool of skill and knowledge, moreover, which (in spite of the typically limited range of outputs produced at any moment in time) enabled them to shift from the production of one sort of machine to another with comparatively minor modifications. Indeed, we find here one of the most important cases of a single learning process lying at the heart of economic development. What was learned was the capacity to produce and employ machinery over a wide range of productive activity.[28]

By simple extension this analysis may help to explain the greater resiliency of industrial economies to secular changes in demand by comparison with the often-cited less favorable experiences of under-developed countries.[29] Industrial economies have a much higher proportion of their resources engaged in the production of inter-mediate goods. However, all intermediate goods are not equally important. One particular class, machines (including, of course, the machine-producing machines) is of the greatest strategic import-

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ance. The facilities, skills and techniques acquired with this particular range of intermediate products constitute a major determinant of an economy's capacity to adapt to external changes and to undertake technological innovations on its own initiative. An important dimension of the development process can thus be isolated by examining the disproportionate growth of specific intermediate products.

The discussion so far has assumed more or less explicitly that it was possible to arrange all production processes into "assembly lines", within a firm, or else in some sequence of firms. But it is by no means clear that such orderings are meaningful in a modern economy. Thus fuel oil may be a final consumer good (if it heats a house), an item of fixed cost (if it heats a factory), or an item of marginal cost (if it powers a truck). A board may be used as a consumer good, if it is used as a shelf in a house; as a capital good, if it is used to make a factory partition; as an intermediate good, if it is used for crating a product; as a raw material, if it is used for furniture, and so on. The attempt to sort production processes into a set of assembly lines seems to create extreme difficulties.

On the other hand, the concept of "raw material" or "intermediate product" or "finished goods" may be economically meaningful, used in the context of a particular industry. Thus coal is a collection of different solid fuels, some of which are used by households, some by businesses, and so on. Coal is one of the inputs of power plants, and as such competes with fuel oil, natural gas, and so forth. It is not economic nonsense to consider the market for fuels used by power plants; nor is it nonsense to observe that some plants may be designed to use a single type of coal (are completely specialized) while others may use many types of coal, or may even sometimes use solid fuel, and sometimes liquid fuel or even gas, depending on price. Such plants, with respect to their inputs, are less specialized than power plants which use only one type of coal.

It is in connection with situations of this sort that the concept of "horizontal specialization" becomes useful. A situation involving horizontal specialization exists whenever commodities may be grouped, either because they are all sold by a definable group of sellers, or bought by a definable group of buyers. The concept of "a definable group" frequently overlaps or coincides with some technological considerations. In fact, such groupings are unavoidable if economists are to talk about entities such as "the coal industry", "the steel industry", the "chemicals industry", which sell

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literally thousands of different commodities differing only "slightly" one from the other. In discussing "horizontal specialization", we are really talking about specialization in cases where firms produce a range of products, or buy a range of products which are very much alike with respect to some observable (economic or non-economic) criterion.[30]

To return to the problem raised at the outset of the paper, it would seem that firms which are less specialized horizontally are more complex; one aspect of complexity, then, relates precisely to the extent of horizontal specialization, so that except as an alternative to the rather barbarous "horizontal skill", it is redundant.

Consider the set of markets for different types of steel. Sellers are steel producers, and buyers steel users. With regard to this set of markets, a group of sellers (say sellers of one country) is specialized if the average number of types of steel sold per firm is small. A set of buyers (say buyers of one country) is specialized, if, on the average, its members buy, on the average a small number of kinds of steel. Speaking of this market, Kindleberger asserts that "great specialization can be achieved only at the cost of flexibility". By this he means that British firms, in particular, bought only Bessemer steel and not Siemens-Martin acid steel. Hence, when the price of the latter dropped, the less specialized (German) firms could substitute cheaper grades, while the more specialized (British) firms could not.[31]

III. Implications for the Development Process

The foregoing argument has been mainly taxonomic, but the purpose has not been taxonomic. We shall therefore suggest several conjectures about problems of major importance to economic history and economic development, to illustrate the kinds of problems to which our theory of specialization applies. Limitations of space and time preclude an extended discussion. We shall discuss only one group of problems in this paper, but we suggest that the others, too, might more readily be solved with the theoretical apparatus presented here than with the more traditional Marshallian techniques. In listing the following assertions, we are not passing judgement upon their validity, but only calling attention to their economic interest.

(A) In early stages of a country's industrialization, firms tend to specialize; in later stages they diversify.

(B) The more industrialized a country is, the less its dependence upon particular sources of materials (the less its specialization with respect to inputs).

(C) The more industrialized a country is, the more skilled (the less specialized) its machines become (backward countries use relatively simple machinery).

(D) The more industrialized a country is, the more specialized labor becomes within the production process, and the less the horizontal specialization of labor is (on any job, the worker carries out fewer activities, but the larger the number of industries in which this job exists).

(E) The more industrialized a country is, the more diversified will be the composition of its exports.[32]

(F) Specialized firms are more vulnerable to changes in demand, *ceteris paribus*, the closer their output is to the final product stage in a production process.

We shall introduce our discussion with a classical problem in the theory of probability: the problem of gambler's ruin. In brief, it is shown that if two gamblers have equal probabilities of winning a game, the gambler with the smaller initial capital will, on the average, be ruined before the gambler with the larger initial capital.[33]

Suppose conditions of pure competition in world markets, in which there is a large number of commodities, the prices of which move up or down at random from one date to the next. If inflation or deflation does not exist, the probability of increases and of decreases in individual prices are equal. Suppose exporters face steady domestic costs, and product prices are fixed in world markets. Then at any moment for each good there is a certain price drop which would force an exporter to stop producing. If an exporter produces several commodities, then he will go out of business when all prices reach these shut-down levels. From this point of view, the total amount by which prices must decrease in order to drive the exporter out of business is comparable to the gambler's initial capital. One firm will have a longer expected "duration of game to ruin" than another if it starts with a larger initial capital. This may happen because initially its costs are relatively low. Alternatively, it may have a larger initial capital because (even though its costs are no lower) it has a greater number of exportable commodities for sale. In this case, the reasoning of the gambler's ruin problem will apply with one proviso: that the probabilities of increases or decreases in the individual commodities are independent.

This reasoning, so far, merely suggests that under somewhat restrictive assumptions, skilled (horizontally diversified) firms are more apt to survive a given length of time than specialized firms. It may, however, be turned into a proposition about economic development. Suppose that as a country industrializes, the average skill (diversification) of firms increases. Then at any particular moment, the firms of less industrialized countries stand a greater probability of ruin than those of more industrialized countries. In other words, the earlier a country has started to industrialize, relative to another, the more likely it is to remain at a competitive advantage in the future.[34]

Suppose, moreover, that the probabilities of price changes for different commodities are related in the following way: the more industrialized the country, the less likely that a price change for one commodity will be associated with a similar change for another.[35] Then the less industrialized a country is, the more it resembles a one-commodity economy even if it actually produces many commodities; the more industrialized it is, the closer it approaches the conditions of the "gambler's ruin problem". This possibility is known in economic development literature as the "dependence of under-developed countries on a few specialized raw materials".

A second problem relates to the decline of the handloom weavers and the Luddite movement. Suppose that as industrialization proceeds, individual job-descriptions in plants become more specialized, but individual specialized jobs spread through a wider variety of industries. (Vertical specialization of labor increases while horizontal specialization declines.) Then at an early stage of industrialization, workers belonging to a particular trade are highly skilled, but lack alternative employment, at a later stage they are less skilled, but have alternative employment. Hence, on the gambler's ruin principle, labor, due to its job immobility, actually has more to lose from technological change in a backward than in an industrial economy. Luddites, then, are a phenomenon primarily of early periods of industrialization.[36]

We have suggested above that labor has become more specialized and machinery more skilled. If the skilled workers of early industrialization become "Luddites" when confronted with new technology, we might expect the owners of skilled machinery to become "Luddites" under modern conditions. There is no obvious way in which they have shown increased "political" objections to technological change. If they have not, we suggest that it would be inter-

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esting to know why not. One conjecture would be that for firms, the increased skill is two-dimensional; increased vertical skill makes an industry vulnerable, while increased horizontal skill does not. If the "assembly line" view of an economy is discarded, most firms will be viewed as producing mixtures of intermediate and finished goods. Then a technological change will not cause an entire industry to perish (as the Italian and Flemish textile industries did), but will only affect some part of its markets or processes. Industrialization, then, appears to increase "flexibility" (for otherwise machine owners would be Luddites). This word, in deliberate quotation marks, is generally meaningless. We suggest that "flexible" may mean "having little horizontal specialization". If so, here is another real problem to be dealt with in terms of specialization.

The foregoing two paragraphs will, we hope, prove annoying to economic theorists and historians alike. To the former we shall answer: There is no adequate explanation of either the equilibrium or the optimal number of commodities[37] used by a firm or an economy, and the theory of specialization has hardly changed since Adam Smith. If these propositions are wrong in theory, we hope theorists will become annoyed enough to correct us

To the latter we shall say: a variety of assertions is made in the literature about the appearance and disappearance of industries, labor skills, and machine processes. These changes may occur as a result of non-economic phenomena. (For instance, the Middle East stopped being a farm area when its irrigation was destroyed by war and salinization. Pennsylvania stopped mining iron because Minnesota suddenly turned out to have very large deposits.) But in part they have occurred for economic reasons. It would be helpful to know, as a matter of fact, when the appearance and disappearance of industries was due to economic factors; and how much can actually be known about the extent of specialization at various periods of history. The assertions cited in this paper may not be true, but they are interesting. If they are true they have important consequences.

Conclusions

The conclusions to be drawn from this analysis are in part of a theoretical nature: it is possible to apply a consistent set of terms to problems involving the number of products produced by firms; the number of inputs used by firms; and the amount of vertical integra-

tion achieved by firms. This terminology reveals a number of interesting problems which are ordinarily glossed over by theories which assume, in the main, single-product firms producing homogeneous, divisible products for final consumers. On purely theoretical grounds, these problems are interesting enough to warrant further exploration of the concepts advanced here.

In addition, however, the analysis raises certain practical considerations concerning the establishment of new firms in underdeveloped countries. A developing country necessarily recapitulates some of the history of countries which have developed before it. For example, indices of per capita income, percent of population in manufacturing, etc., will necessarily follow, in some sense, the path of earlier countries. It is natural to consider whether its indices of specialization and skill must repeat the history of predecessors.

Consider the suggestion advanced about labor and machines. It has seemed that the first effect of industrialization in the west was to decrease the skill (increase the specialization) of labor; and only later to increase the training required of labor. In the case of machinery (apart from the use of machines to do heavy work), the tendency has been to increase first the skill and later the "training" of machines. If industrialization follows this pattern generally, it might well be the case that developing countries could postpone the creation of an educated labor force until relatively late in their program. If, on the other hand, it is possible for the developing country to bypass certain stages of the history of predecessors, the date for an intensive educational effort should be advanced. Moreover, "technological policy" might well militate in favor of the adoption of relatively simple industrial processes in the first case, and in favor of "truly modern" plants only in the second.

A second group of problems would bear upon protectionism in developing countries. If, indeed, diversification of output increases with industrialization, and if diversification decreases the risk of failure of firms in a world market, then firms in a developing country face relatively high probabilities of failure in any competition with firms of developed countries, and can succeed only if they are protected—even if comparative advantage may work in their favor in some sense. But we cannot argue that this view is correct. It may be merely another in the long literature of plausible but indefensible claims about development processes.

Finally, we have laid considerable stress upon the importance of firms which make some mixture of intermediate and final goods.

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The problems of such firms tend to disappear in the literature which deals with national accounts, i.e., final demand. But it may well be that a key to industrialization lies in the development of firms which use a common technology to make both intermediate and final goods: such firms are efficient means of diffusing new techniques through an economy. If it is possible for a developing country to assist in the growth of such firms, it may have a powerful instrument for economic growth. We do not suggest that such assistance can in fact be offered. We do suggest that the kinds and degrees of specialization suitable to an economy may depend upon the level of development of that economy; and that attempts to establish unsuitable specialization patterns may lead to unviable economic organizations.

[1] In "Increasing Returns and Economic Progress," *Economic Journal* December 1928, p 539

[2] See Nathan Rosenberg, "Technological Change in the Machine Tool Industry, 1840–1910," *Journal of Economic History,* December 1963, pp. 414–443, *Twelfth Census of the United States* (1900), Part IV, Volume X, "Manufactures"; *Special Reports of the Census Office* (1905), Part IV, "Metalworking Machinery", J H Clapham, *An Economic History of Modern Britain* (Cambridge University Press, Cambridge, 1959) Volume I, Chapter V

[3] See for example, Murray Brown and Nathan Rosenberg, "Patents, Research and Technology in the Machine Tool Industry," *The Patent, Trademark and Copyright Journal of Research and Education,* Spring 1961, pp 1–15

[4] H Leibenstein, *Economic Backwardness and Economic Growth* (New York, Wiley, 1957) Chapter 7, especially page 80; see also his *Economic Theory and Organizational Analysis* (New York, Harpers, 1960) Chapters 7–8

[5] George Stigler, "The Division of Labor is Limited by the Extent of the Market," *Journal of Political Economy,* June 1951, pp. 185–193

[6] Leibenstein, *op cit*, p 80

[7] According to this definition, then, someone who was completely unspecialized—completely self-sufficient—would also have to be very highly skilled, a consideration which doubtless goes a long way towards explaining the limited number of genuine Walden Pond enthusiasts

[8] This definition of skill coincides best with the antithesis craftsman-factory worker, in which a worker capable of performing every step in an industrial process is replaced by a group, each member of which performs a single activity. Actually, in a broader sense "skill" may be considered a multi-dimensional property, combining skill (in this narrow sense) with aptitude for a particular occupation. Thus plumbers and doctors may be equally skilled (in the sense of performing an equal number of activities), but since the two have different aptitudes, which the community values differently, the two command different incomes. This distinction between training and skill must be understood. We do not talk about training, and feel that confusion in the literature occurs in part because training and skill have been wrongly associated. Our definition is in line with *The Wealth of Nations,* which asserts that division of labor gives rise to "differences of talent more important than the natural ones." "The difference

between the most dissimilar characters, between a philosopher and a common street porter, for example, seems to arise not so much from nature as from habit, custom, and education By nature a philosopher is not in genius and disposition half so different from a street porter, as a mastiff is from a greyhound, or a greyhound from a spaniel, or this last from a shepherd's dog." Adam Smith, *The Wealth of Nations* (Random House, New York, 1937), pp 15–16

[9] This usage has been anticipated in P Sargant Florence's interesting book, *Investment, Location, and Size of Plant* (Cambridge, 1948), especially in Chapter 3

[10] Apart from a failure to distinguish between hand-tools and machines, which need not be labored here

[11] We repeat that we ignore "training " It is not necessary to our argument

[12] Smith was very much troubled by the conversion of the human input into a servomechanism "The man whose whole life is spent in performing a few simple operations, of which the effects too are, perhaps, always the same, or very nearly the same, has no occasion to exert his understanding, or to exercise his invention in finding out expedients for removing difficulties which never occur He naturally loses, therefore, the habit of such exertion, and generally becomes as stupid and ignorant as it is possible for a human creature to become .   His dexterity at his own particular trade seems to be acquired at the expense of his intellectual, social, and martial virtues But in every improved and civilized society this is the state into which the labouring poor, that is, the great body of the people, must necessarily fall, unless government takes some pains to prevent it " Adam Smith, *op cit , 734–35*

[13] Fritz Machlup *The Production and Distribution of Knowledge in the United States* (Princeton University Press, Princeton, 1962), pp 380–82; and Gladys Palmer and Ann Miller, "The Occupational and Industrial Distribution of Employment, 1910–1950," in W Haber, F. H Harbinson, L R Klein, and G L Palmer (eds), *Manpower in the United States* (Harper and Brothers, 1954), p 87

[14] Charles Babbage, *On the Economy of Machinery and Manufactures* (London, 1838) observes (p 17) that "the higher the (training) required of the workmen in any one (activity) of a manufacture, and the smaller the time during which it is employed, so much the greater will be the advantage of the separating that (activity) from the rest, and devoting one person's attention entirely to it " And (p 149) "we avoid employing any part of the time of a man who can get eight or ten shillings a day by his skill in tempering needles, in turning a wheel, which can be done for sixpence a day." (Words in parentheses have been changed to conform to the usage in this article)

[15] It is possible that the eventually decreasing capital/output ratios reported by Leontief, Kuznets and others are explainable in terms of better educated machines

[16] The American chemical and oil industries possess 50 "maintenance" employees per 100 "production" employees *Factory Management and Maintenance* (McGraw-Hill, New York, 1958) p 183

[17] James Bright, *Automation and Management*, (Division of Research, Graduate School of Business Administration, Harvard University, Boston, 1958) Chapter 12 is concerned in part with this matter, and in part with the question of whether workers of a given degree of specialization require more training (in his terminology *skill*) as technology changes He also

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refs to changes in the importance of maintenance workers (i.e. workers not in an ordering with machine activities) and production workers (i.e., workers)

[18] Young, *op cit.*, p 537.

[19] In the context, the common usage for the opposite of vertically specialized would seem to be vertically *integrated*, with *integration* the concept corresponding to *skill*, where the agent is a firm We have hesitated to use this term here, because it has become associated with issues of competition and monopoly, with which we are not much concerned.

[20] George Stigler, *op cit*, p 193, G. C Allen, *The Industrial Development of Birmingham and the Black Country, 1860–1927* (London, 1929) pp 56–57, 116–117 See also the article by John D. Goodman, "The Birmingham Gun Trade," in Samuel Timmins (ed), *Birmingham and the Midland Hardware District* (London, 1866), pp 381–431

[21] S Fabricant agrees with Stigler that "as an industry grows in size, there is a tendency for it to disintegrate vertically." ("Study of the Size and Efficiency of the American Economy" in E. A G. Robinson (ed) *Economic Consequences of the Size of Nations* (Macmillan, London, 1960), p 49) If so, it might be explainable in terms of gradual branching of assembly lines

[22] "The Ford Motor Company's engine plant at Cleveland, Ohio, is in a very real sense one enormous specialized machine tool intended to take raw metal, cast it, and machine it into finished engine blocks and heads, by means of fully automatic and automated machinery." Robert Woodbury, *History of the Grinding Machine* (The Technology Press, Cambridge, 1959), p 121

[23] Marvin Frankel, "Obsolescence and Technical Change in a Maturing Economy," *American Economic Review*, June 1955, pp 296–319, Don Gordon, comment thereon, and Marvin Frankel, "Reply," *American Economic Review,* September 1956, pp. 646–656

[24] *Essays in World Economics* (Oxford, 1959), pp. 173–174 The example is also found in Carlo Cipolla, "The Decline of Italy," *Economic History Review,* 2nd Series, Volume V, pp 178 ff

[25] Rosenberg, *op cit*

[26] See John L Hayes, *American Textile Machinery* (Cambridge, 1879), pp. 55–62

[27] We are disregarding here cyclical phenomena and therefore also the well-known short-run instability of the capital goods sector Our interest and emphasis here is upon secular shifts

[28] The suggestive analysis by Edith Penrose of the economics of diversification and, in particular, her treatment of the firm as a "pool of resources," is highly relevant to a further exploration of this subject See Edith Penrose, *The Theory of the Growth of the Firm* (Oxford, Basil Blackwell, 1959). especially Chapter VII.

[29] " . . once a country has reached a certain stage of development, it does appear to acquire (or to be able to acquire) a kind of resilience against changes in its comparative advantages One of the great advantages of "advanced" specialisms is that they carry with them the *capacity* of doing other things, thus, if an 'advanced' country is driven off one specialism. it does not find it insuperably difficult to grow another." J R Hicks, *op. cit.*, p 173

[30] In current usage, a firm whose output is not specialized has diversified We shall use "skill" in place of "diversification" to stress the symmetry of our argument.

[31] C. P. Kindleberger, "Foreign Trade and Economic Growth," *Economic History Review*, 2nd Series, XIV, December 1961, p 299.

[32] We took from Joseph Coppock. *International Economic Stability* (McGraw-Hill, New York, 1962), Table A–2, figures on 1957 per capita incomes, on the one hand, and the largest, and three largest exports as percent of total exports on the other, for 62 countries These turned out to have negative correlation of about 25, which is significantly different from zero at about the 03 level It is thus a fact (as economic facts go) that the more developed a country was, the *less* was its export specialization It is not a fact of overwhelming importance, since this type of specialization would "explain" only about 6 per cent. of the variations in real income

[33] William Feller *An Introduction to Probability Theory and its Application.* (2nd ed , Wiley, 1957, New York), Volume 1, Chapter XIV

[34] See Edward Ames and Nathan Rosenberg. "Changing Technological Leadership and Economic Growth," *Economic Journal,* March 1963.

[35] It will be recalled that the business cycle is being disregarded here.

[36] Our conclusion is here reached on the basis of exploring one dimension only of the process of industrialization The decline in worker protest movements is also further reinforced by other phenomena associated with industrialization Thus, industrialization appears to bring with it the growth of organizations and institutional procedures for the orderly settlement of disputes All highly industrialized societies in the non-communist world possess procedures for the channelization and resolution of worker grievances, collective bargaining machinery for the determination of wages, hours, promotion, lay-offs, fringe benefits, etc , and recourse to specific agencies for the mediation and arbitration of disputes. Therefore, worker protest may be regarded (contrary to Marx) as reaching its peak in the earlier rather than the later stages of industrialization, when workers have not yet adjusted to the discipline and coercions of factory life, when the conflict between the old and new forms of economic organizations creates the greatest psychological stresses, when the worker has not yet acquired the vested interests in the form of rising per capita incomes eventually generated by an industrial society, and when the machinery for the resolution of industrial conflict has not yet been developed Cf. Clark Kerr *et al., Industrialism and Industrial Man* (Harvard University Press, Cambridge, 1960), especially chapters 7 and 8

[37] Since everything which has a price is a commodity, the optimal number of commodities includes an optimal number of processes