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An Engineering-Oriented Approach to the Adoption Technology

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AN ENGINEERING-ORIENTED APPROACH TO THE ADOPTION OF TECHNOLOGY

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AN ENGINEERING-ORIENTED APPROACH TO THE ADOPTION OF TECHNOLOGY

Abstract

Two main facets of the problem of technology change are analyzed in this paper: the engineering principles behind new technology and their adoption by industry. Simplifying assumptions are made of other facets of the problem, such as the discovery of new technologies by entrepreneurs, the use made of them by workers, and the institutional milieu in which they are adopted.

The adoption of technology will be formulated as models of rational (i.e., profit maximizing) entrepreneurial choice guided by market price information (i.e., wage, interest rate, input costs, and product price) when an industrial production function (IPF) is given.

The IPF resembles the aggregate neoclassical production function $Q=f(K, L)$ which is abstract and general. IPF differs from the "abstract" production function because it represents the "technology shelf" of a particular industry (the brick industry here). An investigation is made of the engineering reality of brick production in order to deduce, on the one hand, the engineering principles that lie behind the IPF, and, on the other hand, the IPF itself. The combination of IPF and models of rational choice constitute the theoretical framework in our approach to technology adoption. The empirical implementation of the theory centers in the use of the basic economic data collected for a finite number of firms of an industry.

This paper was prepared as an introductory chapter of a forthcoming monograph on technology adoption which uses the brick industry in Taiwan (Republic of China) as a case study. It is hoped that the methodology may be transferred to other industries in other countries.

Introduction

"The economic growth of nations within the last two hundred years represents a process within the framework of a new economic epoch....The epochal innovation that distinguishes the modern economic epoch is the extended application of science to the problems of economic production. We may call this long period the 'Scientific Epoch' (during which) rapid growth of science and recognition of its usefulness brought about a conscious and systematic application of basic scientific discoveries to problems of economic production and human welfare....The application of science meant a proper climate of human opinion. In this connection it is particularly important to stress the interrelations of technological, social and spiritual change....Application of science via technology would not have taken place without changes in social institutions."[1]

The above historical vision of Professor Kuznets conveys two essential messages on technology change. On the one hand, technological change is a historical process that lies at the heart of economic growth of the modern variety. On the other hand, research in technology change is difficult because the process involves such diversified areas of knowledge as: the scientific and engineering principles, their discoveries (e.g., through R & D and channels of technology dissemination), their adoption and application (i.e., the experimental assessment of their feasibility in terms of production efficiency immediately and human welfare ultimately), economic agents with new opinions and spiritual values

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[1] Simon Kuznets, Modern Economic Growth

(e.g., entrepreneurs with new incentives, labor with new skills and government officials with new roles), and new institutional arrangements as organizational devices (e.g., the market and price system for capitalism).

In view of the complexity, any economic research on technology change must, by necessity, be selective of its analytical emphases. From the five dimensions of technology change mentioned above (i.e., the engineering principles; their discovery; their adoption; the economic agents; and the institutional and organizational devices), the selection of an analytical focus is delimited, first of all, by the nature of the inductive evidence which one intends to use. In our approach, this evidence consists of information obtained from field trips to and subsequent questionnaire returns by some 200 brick factories in the Republic of China.[2] Thus, formal economic models on technology change will have to be designed for the analysis of a multiple-firm industry in a developing country.

With the problem characterized in this manner, a number of issues must be ruled out immediately as unsuitable. The "formalism" of the model makes it difficult to deal with issues related to formation of economic agents (i.e., the quality and the background of the entrepreneurs, the education and skill of labor, and the policies adopted by the government officials). Similarly, we shall also not be concerned with the discovery and the dissemination of engineering information (e.g., through R & D and/or international transmission of technology). Issues related to R & D and "patent rights" are unimportant to the brick industry in the

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[2] A detailed description of the sample returns will be given in a later chapter.

developing country of Taiwan. On the "institutional aspect," our choice in the analysis of a multiple-firm industry renders it inconvenient to analyze any market imperfection. Thus, in our approach we shall assume *perfectly free technological information in a competitive industry*.

On the positive side, our research emphasizes two facets of technological change, namely the *engineering principles* and the *adoption of technology*. By the "engineering principles" we mean the engineering reality of brick production, i.e., how bricks are made from the standpoint of production engineers. By the "adoption of technology" we mean "technology choice," i.e., the analysis of the causation factors affecting rational (or profit maximizing) entrepreneurial technology choice. Since we have chosen to neglect the quality of entrepreneurs, imperfect markets and/or technological information (see above), the "causation factors" are limited to factor prices (i.e., wage rates, rent, interest rates and cost of raw materials). This type of problem is obviously most suitable for analytical economic models.

The simplest model is, in fact, based on the traditional individual firm analysis. When a production function (e.g., in the form of $Q=f(K,L)$) and product as well as factor prices (i.e., p for product, w for wage, and π for interest rate) are postulated, the maximization of profit leads to static equilibrium values of outputs Q and inputs, K,L. The comparative static analysis then investigates the impact of the variation of (p,w,π) on the equilibrium magnitudes. We can interpret the production function as a "technology shelf" and the variations of (p,w,π) as determined exogenously by the forces of economic development--e.g., in an LDC, wage increases and interest rate declines through time. Then the comparative static approach amounts to an analysis of the adoption of technology. It is evident that, for economic analysis, some such framework of reasoning is indispensable in any analytical approach (see Section I).

Despite its simplicity, the traditional economic analysis is deficient in that the abstract production function Q=f(K,L) fails to reflect certain very essential engineering principles particular to the brick industry. A brief sketch of the engineering realities of production in the brick industry will be undertaken in Section II. It will then be apparent that technology in this industry really means some very concrete engineering facts (e.g., sizes of firm, structure of kiln, sunning ground capacity, fuel and manpower utilization) and that, through time, technology changes are manifested mainly in terms of these diversified engineering dimensions. The major benefit derived from field trips is the identification of the specific engineering techniques which helps us determine the phenomenon characteristic of technology change for a particular industry (e.g. the brick industry).

The two facets of the problem just outlined, i.e., the technology adoption and the engineering principles, must be blended into the same economic model. For this enterprise, it is clear that there is a basic difference between "engineering economics" on the one hand and "economics of technology change" on the other. The former, which is an art practiced by engineers, attempts to incorporate in their blueprints all the engineering dimensions to build one plant that maximizes profits. This is, of course, never the interest of an economist who is concerned primarily with the explanation of social phenomena observable through statistical information revealed by the coexistence of a multitude of large and small, old and new, competitive firms (i.e., firms using technologies with different vintages) that make up the brick industry. For this reason, the economist must be preoccupied with a small number of engineering principles--rather than a host of engineering details. The aim of this chapter is to show how we intend to blend "technology adoption" and "engineering principles" in the same economic model (or models).

The design of the model is based on a three-step reasoning. In the first step, three "engineering principles" will be identified as essential for the brick industry. These are: (i) the substitution of labor by other sources of energy in the performance of work (Section III), (ii) capital oriented efficiency of large-scale production (Section IV), and (iii) the consistency in production scheduling (Section V). In the second step, the engineering foundation of the production function will be investigated. Thus, our position is that the production function approach, familiar to the economist, should not (and, indeed, cannot) be abandoned. What is needed here is to construct special production functions which "capture" the essence of the engineering principles. When this is done, the final step is to carry out the familiar comparative static analysis. An assessment of this approach will be given in the last section (VI).

Section I: Economic Framework of the Adaptation of Technology

A basic requirement of any economic model for a multiple-firm industry is that it can explain the coexistence of a finite number (n) of firms for which we can observe the triplet of labor (L_i), capital (K_i^t) and output (Q_i)

1.1) $(Q_i, K_i^t, L_i) \quad i = 1, 2, \ldots .n$

Notice that a superscript "t" is used to identify the vintage of the capital

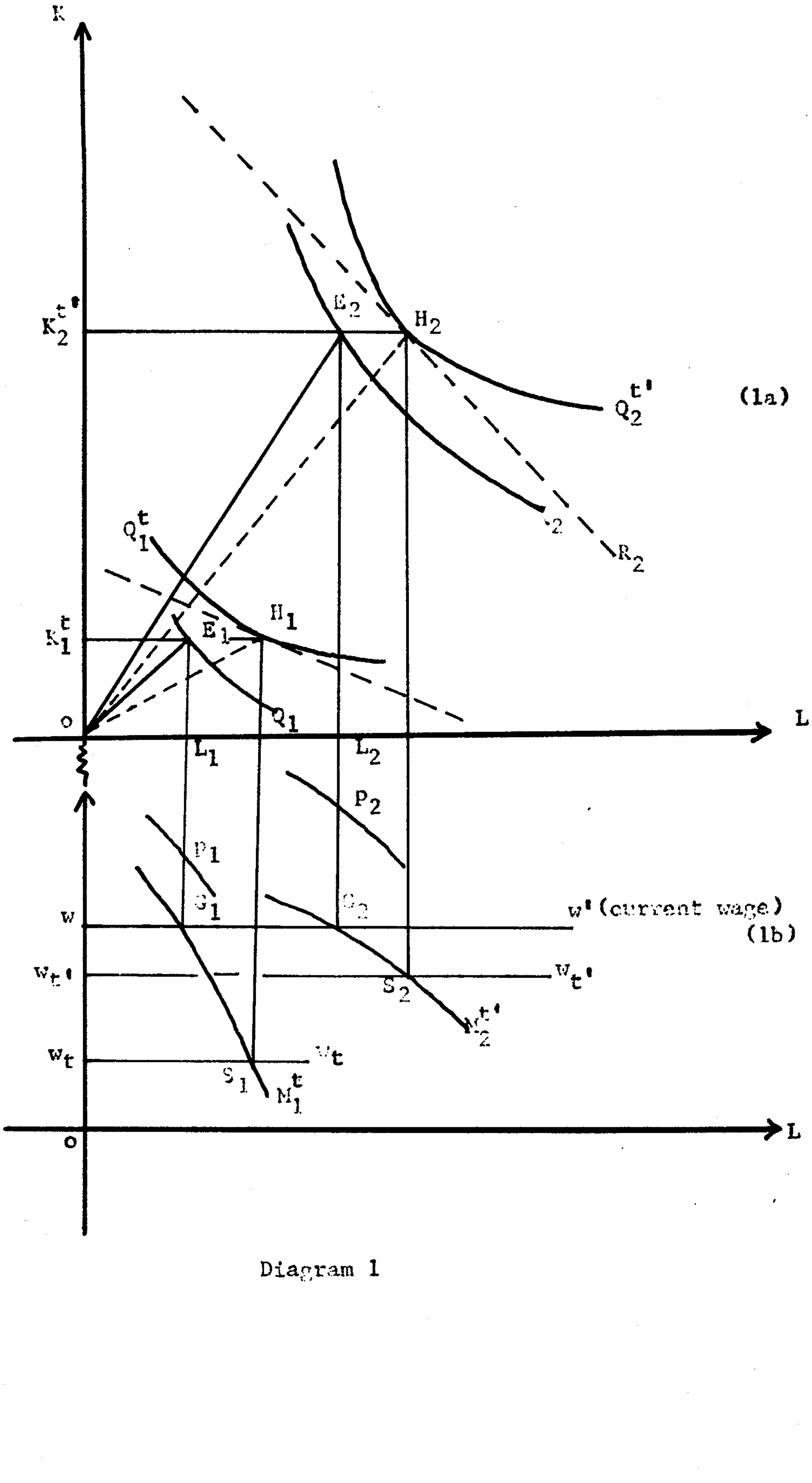

K
$K_2^{t'}$
K_1^t
o
L
E_2
H_2
$Q_2^{t'}$
(1a)
Q_2
R_2
Q_1^t
H_1
E_1
Q_1
L_1
L_2
P_2
P_1
G_1
G_2
w
w' (current wage)
(1b)
$w_{t'}$
$W_{t'}$
S_2
$M_2^{t'}$
w_t
W_t
S_1
M_1^t
o
L

Diagram 1

stock (e.g., $t = 1952$ would mean that the factory was build in the year 1952). Let a production function be postulated

1.2) $Q = f(K,L)$

This is shown by the production contour map of diagram 1a in which K(L) is measured on the vertical (horizontal) axis. The coexistence of two competitive firms ($i=1,2$), with capital stocks (K_1^t, $K_2^{t'}$), is shown by the short run equilibrium imput points (E_1, E_2) with the employment of (L_1,L_2) units of labor and producing (Q_1,Q_2) units of output. That (E_1,E_2) represents short run competitive equilibrium is emphasized further by the fact that they are vertically lined up with the pair of points (G_1,G_2) in diagram 1b. In this diagram, the current wage rate is "w" and (G_1,G_2) are the points of intersection of the marginal labor productivity curves (M_1^t, $M_2^{t'}$) with the horizontal wage line ww'. Thus, the observed triplets in (1.1) represent short run competitive equilibrium in a competitive industry.

This traditional analysis has the obvious advantage that it can explain a number of "stylized facts". Think of K_1^t as the capital stock of a smaller firm (i.e., $K_1^t < K_2^{t'}$). For a smaller firm diagram 1a shows that the outputs and employment are smaller ($Q_1 < Q_2$ and $L_1 < L_2$) and that the smaller firm operates with a lower capital per head (OE_1 less steep than OE_2) and a lower labor productivity ($p_1 < p_2$ in diagram 1b). This is an important advantage because (1.1) constitutes the most important set of data for economists.

A theory of technology change, consistent with the above competitive equilibrium interpretation of (1.1), centers on the explanation of the adoption of (K_1^t, $K_2^{t'}$) as an historical event. For this purpose, think of the capital K_1^t of the smaller firm as representative of a technology of an older vintage (e.g., $t=1930 < t'=1950$, i.e., the small firm was constructed twenty years earlier). Let $(w_t, w_{t'})$ represent the real wage (in terms of the price of output as a numeraire) and $(\pi_t, \pi_{t'})$ represents the rates of interest prevailing at (t, t') respectively. The real wages $(w_t, w_{t'})$ are indicated on the vertical axis of diagram 2b. In the year t, the equilibrium position of the smaller firm was built showing an input point H_1 in diagram 1a. The capital stock K_1^t was adopted because it represents long run equilibrium relative to the factor price ratio w_t/π_t (i.e., the slope of the dotted line H_1R_1 tangential to the production contour at H_1) and the real wage w_t (i.e., H_1 lies above the point S_1). Thus in our approach a theory of technological adoption amounts to a theory of rational (i.e., profit maximizing) historical choice of vintage capital (e.g., K_t^1).

Reasonings about technological adopt in this framework can be linked with economic development directly when the latter is interpreted as "producing," to the individual industry certain exogenous impact on products and factor prices. As shown in diagram 1, t' - t years later, the larger and more modern firm was built with a long run equilibrium position indicated at H_2 (diagram 1a) or S_2 (diagram 1b). This firm came into existence because it was warranted by the higher real wage $(w_{t'} > w_t)$ and relatively lower interest rate (H_2R_2 steeper than H_1R_1 in diagram 1a). Thus, a major hypothesis of our theory of technology change is that technology adoption is sensitive to, or primarily induced by, the long run variation of real factor prices brought about by economic development.

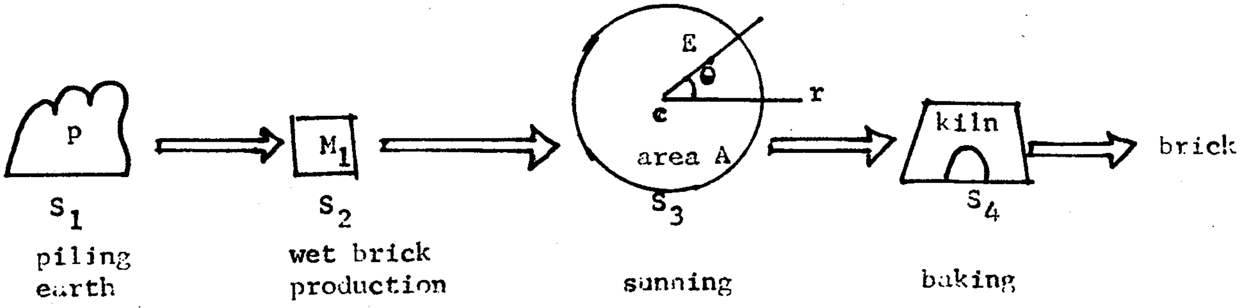
In our approach "technological adoption" is viewed realistically as a historical process of " marketing" phenomena involving rational choices of capital vintages by firms. This familiar framework can be linked directly with the essential economic data (1.1) on the one hand and with economic development on the other. The deficiency of our approach, however, is all too apparent. There must be no non-homogeneity of (K,L,0). There must be no market imperfection. Technology information summarized by the production function (1.2) must be perfectly available and free. The theoretical simplication is necessary as a first approximation because it allows us to explore more deeply our next topic, namely, the reality of the engineering principles of production in the brick industry.

II) The Engineering Process of Brick Production

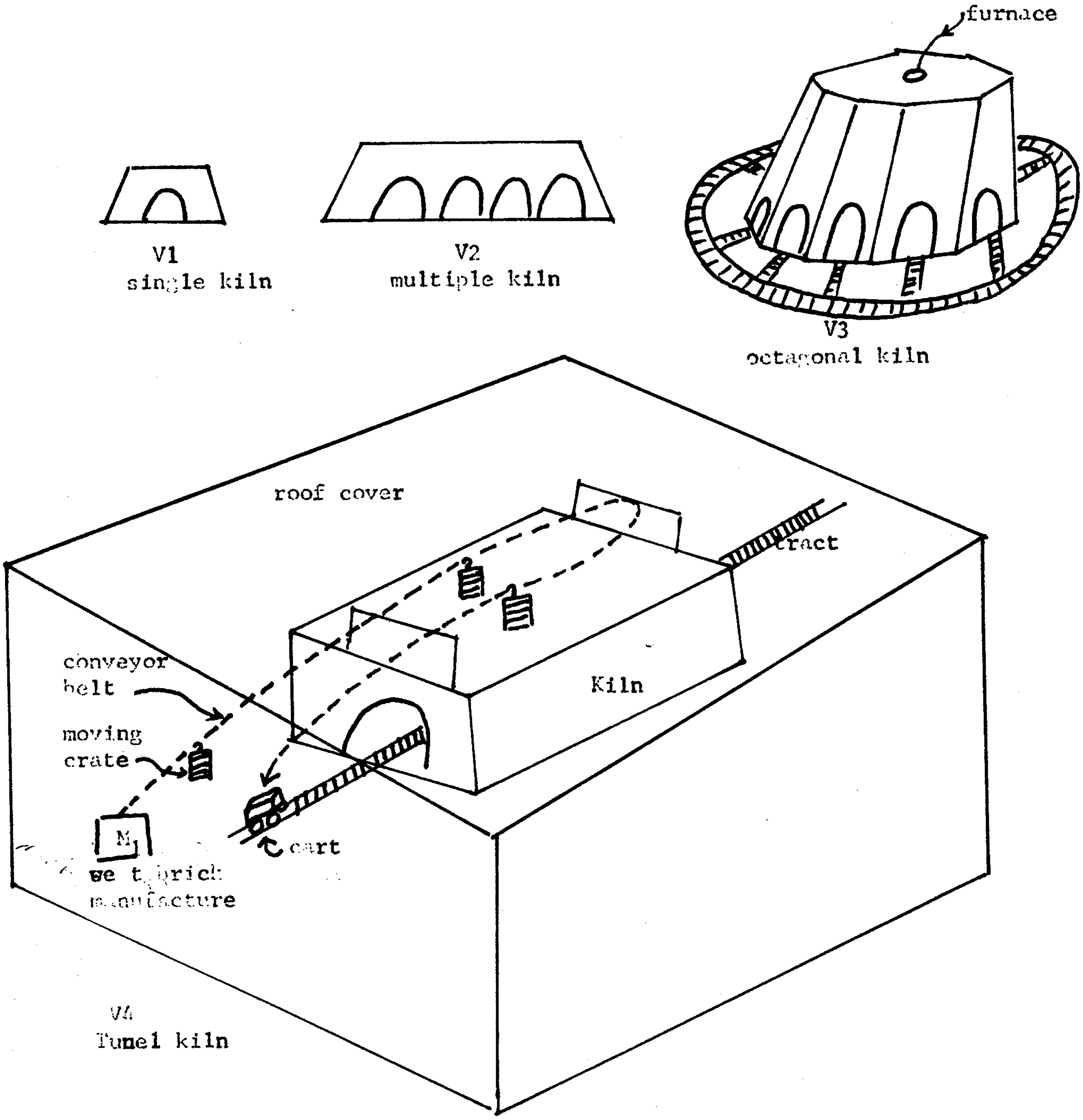
Four Steps in Brick Manufacture

There are four basic steps (S1, S2, S3 and S4) in the production line of brick manufacturing--see diagram 2a. S1 is earth piling during which the basic raw material for bricks (i.e. the earth) is piled up near the place where wet brick is formed. S2 is wet brick formation during which, with the aid of simple machines "M_1" (i.e. for mixing the earth with water, stirring and molding), wet bricks are made via a production line. S3 is sunning during which the wet bricks are transported to the sunning ground (depicted as an area of a circle with a center at C and a radius r) where they are left to dry in the sun for a few days, to complete the first chemical process. S4 is baking during which the sun-dried brick are shipped into a kiln (K) (thorough an opening gate) where they are baked for another few days to complete the second chemical process. Afterwards, the finished products Q (i.e. the baked bricks) come out of the production line.

Thus the manufacture of brick involves both mechanical processes (i.e., moving the earth, the bricks, and forming the wet bricks) and chemical processes (i.e., sunning and baking). The major current inputs are labor and fuel--the "earth" is not a major real cost element. The major capital goods are the kiln, the sunning ground, and the machinery, of which the kiln is by far the most important item from the technological as well as financial investment standpoint.



(2a) Production line of brick manufacture



(2b) vintages of kiln

Diagram 2

Vintage Capital

The evolution of brick technology is manifested primarily in the kiln design. There are basically four types of kilns: the single kiln (VI), the multiple kiln (V2), the octagonal kiln (V3) and the tunnel kiln (V4)--see diagram 2b. They represent four vintages of capital in that order. On the one hand, the single kiln (V1) represents the oldest vintage which is by now nearly extinct. On the other hand the tunnel kiln (V4) represents the most modern technology adopted by relatively few modern firms. Most of the existing firms in Taiwan have multiple or octagonal kilns (V2 or V3).

The single kiln (V1) has one gate representing one baking compartment. Since it takes time for the kiln to warm up and to cool down before the next load of bricks can be baked, the single compartment means essentially that only one baking shift can go on at any moment in time. The multiple kiln (V2) is an improvement over the single kiln precisely because it has several gates (or baking compartments) which can be ignited separately. In the case with four "gates", for example, a maximum of four different baking shifts, (ie. form shifts that begin at different times) can go on at the same time.

The octagonal kiln (V3) operates on the same principle, each of the eight compartments can be ignited separately. A single furnace is located in the middle of the kiln and coal can be fed in from the top. The improvements of the octagonal kilns over the mutiple kilns can be seen in at least three ways. First, the gates and the compartments are much larger and tracks are build around the kiln leading to each compartment. This allows the workers to work inside the kiln when they load or unload the carts. Second, the kiln is a much more complicated structure because of the centrally located furnace which requires mechanized devices in coal feeding, ventilation and water drainage. Third, because of its octagonal shape, the eight baking shifts operate according to cyclical schedules.

The tunnel kiln (V4) has a rectangular shape with a tunnel in the middle through which tracked carts (with loaded dry bricks) can move from one end to the other. When the wet bricks are formed at M_1, they are loaded on moving crates which hang from conveyor belts (the dotted line in diagram 2b). For the drying process, the carts move slowly on top of the kiln so that, instead of the sun, the wet bricks are now dried by the residue heat from the baking process. When the carts complete the journey at one end of the tunnel, they are loaded on the tracked carts that move through the tunnel for the final baking process. The entire productive line operates under a covered roof.

The tunnel kiln (V4) represents a major technological breakthrough over the octagonal kiln (V3) in several respects. First, the substitution of residue heat drying eliminated the sunning ground as an input. Second, since the 'residue heat process' is covered by a roof, the uncertainly due to weather conditions (i.e. rain and clouds) is also eliminated. Third, the tunnel kiln is larger, in order to have a large area to emanate the residue heat; and more complicated in its internal design, as the temperature inside the kiln must be delicately controlled so that the bricks can be baked without scorching the carts. This requires the replacement of coal with oil as fuel. Fourth, instead of distinct baking shifts (as in V1, V2 and V3), the baking process is now continuous as the loaded tracked carts move smoothly into the tunnel, one after another. Fifth, loading and unloading inside the kiln is eliminated. Sixth to achieve synchronization of a smooth baking process, the production process in the previous steps (i.e. earth piling S1 and wet brick manufacture S2) requires more complicated machinery (M_1) that replaces labor.

Approaches to Technology Change

The above brief sketch of the engineering process of brick production serves at least one purpose, namely, it helps us to identify the essential phenomenon of technical change in the brick industry. From the engineer's point of view, that phenomeon really centers on the evolution of the kiln design. This is what must be explained in a theory of technology change in the brick industry. The economists, however, are not interested in the "morphology" of the kilns nor the mechanical or chemical engineering details. Our primary interest is to explain the evolutionary process, i.e. to understand why the sequence of vintage capitals V1, V2, V3 and V4 are adopted through time in that given order.

The guiding principle relative to our inquiry is to investigate the implications of the above engineering information (i.e., the kiln design) on the production relationship between inputs (i.e., labor, vintage capital, fuels, sunning ground area) and output (i.e., bricks). Obviously, in order to see whether factor price change will contribute to the emergence in the development process of, for example, the tunnel kiln (V4) we must investigate the advantages of V4 in terms of profit calculation. In short, we must translate the engineering information as properties of the production function such as (1.2)--otherwise the engineering details are obviously irrelevant to our inquiry.

Brick manufacturing is a rather simple industry from the viewpoint of production engineering.[1] Nevertheless, even for such a simple industry, the engineering principles of production are quite complicated. The attempt to summarize all these complexities in the "production function" (1.2) will tend to hide rather than to reveal the engineering principle involved. We propose to identify, not one, but three abstract engineering principles which we think are essential for brick manufacture (see Introduction). In the following sections we shall briefly describe these engineering principles and indicate the way we intend to translate these principles as properties of "production functions".

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[1] In our original research plan four industries (brick, textile, shoe and machines tools) are selected. The brick industry is the simplest for several reasons. First it has only four clearly indentifiable steps in the production line--while the other industries have at least double that number. The brick product is more homogeneous--in comparison with shoes, textiles or machine tools which are characterized by "multiple product" within a single firm. Third, there are only four vintages of capital (V1, V2, V3 and V4) in contrast with the more complex forms of technological variations in the other industries. It is hoped that by concentrating on the simple industry first (i.e. brick), our approach will eventually throw light on the other industries too.

III) The Performance of Work

For brick manufacturing, much of the real task of production involves the performance of work, measured in units of foot-pounds or ton-miles by the engineers or physicists. Work must be performed for the piling up of earth (S1), formation of wet bricks (S2) and the loading, moving and unloading of bricks (in S3 and S4). Indeed, the performance of work is the heart of the production of all products when the engineering principles involved are mechanical rather than chemical or biological. It becomes decisive when the product is heavy and bulky such as bricks. Compared with the production of a light and tiny product such as watches, it is obvious that the muscles of the brick worker are more important than his skill or brain. For this reason, the performance of work should lie behind the production function (1.2).

When the performance of work is the most essential production task, there are two types of capital goods, namely, work reduction capital (K_d) and work replacement capital (K_r), operationally defined by

3.1a) $W = D(Q,K_d),\ \frac{\partial W}{\partial Q} > 0;\ \frac{\partial W}{\partial K_d} < 0$ (work demand function)

b) $W = S(L,K_r),\ \frac{\partial W}{\partial L} > 0;\ \frac{\partial W}{\partial K_r} > 0$ (work supply function)

c) $R = \phi(K_r),\ \ \frac{\partial R}{\partial K_r} > 0$ (fuel consumption function)

The work demand function (3.1a) specifies that the amount of work (W) which needs to be performed is positively related to output (Q) and negatively related to the amount of work reduction capital (K_d) (e.g., a wheelbarrow in the sunning of bricks). The work supply function specifies that the amount of work (W) which needs to be performed can, in fact, be performed by unskilled workers (L) and/or work replacement capital (K_r). Typical work replacement capital goods include such items as electric generators and steam engines. These, with the consumption of fuel (R) (i.e., coal, oil, or electricity as specified in the fuel consumption function), can be alternative means of producing work. Thus the work supply function specifies that unskilled labor (L) and work replacement capital (K_r) are substitutable--i.e., the installation of K_r can replace labor in producing the needed work.

Example

The above ideas can be illustrated with the example of the sunning process (S3) in brick manufacturing. Let us assume that the sunning ground is a disk with a radius, r (see Diagram 2a). The number of wet bricks (Q) which can be displayed on the sunning ground is

3.2) $Q = A/a = (\pi/a)r^2$

where "a" is the surface area of one brick. Now imagine that the wet bricks come out of the production line at a point near the center, C, of A (see Diagram 2a) and must be transported by labor to "cover" the sunning ground area, A. More units of work need to be performed for a brick shipped to the edge of the disk than one shipped to a point near C. Thus total amount of work W which needs to be performed is proportional to the moment of A with respect to C, i.e., proportinal to r^3:

3.3) $W = kr^3$ where $k = \frac{2\pi w}{3\ a}$

where "w" is the weight of a typical brick.[1] When the radius "r" is eliminated from (3.2) and (3.3), we have the following work demand function:

(3.4a) $W = D(Q,K_r) = k_o Q^{3/2}$ where $k_o = (2\pi w/3a)(a/\pi)^{3/2}$

b) $A = aQ$

Thus, for the production of a designated amount of output (Q), certain amounts of work (W) and sunning area (A) are needed as inputs from the engineering standpoint. In this example, notice that K_r is missing in (3.4a) when the wet bricks are carried by the bare hands of labor. Generally certain capital goods (baskets, shoulder poles, wheelbarrows, tracked rails and carts) can be used to reduce the work which needs to be performed. The work reduction capital K_r will then appear in the work demand function with a negative partial derivative.

The work, as calculated from (3.4a), can be produced by unskilled labor or an alternative source of energy (oil or electricity) which requires the installation of work replacement capital K_r. For a unit time period (e.g., a day), let the work output per worker (L) be "b" and let the work output of a unit value of K_r be "c" (i.e., c is a product of horsepower and time), then the work supply function is

3.5a) $W = S(L,K_r) = bL + cK_r$

b) $R = dK_r$

where d is the amount of fuel consumption per unit K_r per day. The pair of work demand and supply functions ((3.4a) and (3.5a)) illustrate that, together, they can give a more realistic interpretation of an "abstract" engineering principle than the traditional production function (1.2).

Returning to the general case of (3.1ab), which, when equated, leads to

(3.6a) $D(Q,K_d) = S(L,K_r)$ (or $Q = F(Q,K_d,K_r)$)

b) $R = \phi(K_r)$

where (3.6a) is a production function in an implicit form. Thus output (Q) is a function of (L, K_d, K_r) while fuel is needed to operate K_r. In the special case of the above example, we have

3.7a) $k_o Q^{3/2} = bL + cK_r$ (or $Q = [(bL + cK_r)/k_o)]^{3/2}$

b) $R = dK_r$

c) $A = aQ$

which shows that in the production process, sunning ground areas (A) and fuel (R) are needed as associated inputs in the sun drying process in which the central production task is the performance of work.

Having thus restored the production function (3.6a), we can then go through the traditional formula of comparative static analysis (outlined in Section II) of the adaptation of technology. The types of issues which can be analyzed include the impact of changes in wage, interest rates, rent and fuel costs on the selection of the right type of technology (or capital vintage) whereby the work previously performed by unskilled labor can be either reduced or replaced, in order to maximize profit. For example, intuitively it is apparent that with an increase in real wage and a lowering of interest rates, it will become profitable to install conveyor belts to replace labor.

The production function which we built up in (3.6a) is both "realistic" and "abstract." As compared with the traditional production function (1.2), it is realistic in that it is derived from consideration of certain engineering principles. It is also abstract in the sense that the same engineering principle can be applied to other industries to the extent that the performance of work is the central task of production. It is hoped that the method of analysis is transferable to other industries.

In order to carry out this research, three additional issues must be faced, i.e., theoretical, empirical and econometrical. The theoretical issue centers around an investigation of the properties of the work supply and demand functions (3.1ab) so that the deduced production function (3.6a) will have those familiar properties (e.g., the laws of diminishing returns, economies of scale, and elasticities of substitution) which are essential for the derivation of the traditional comparative static theorems. The empirical issue centers on the classification of capital goods into the work reduction variety (K_d) and work replacement variety (K_r). The econometric issue centers on the derivation of the production functions (3.1ab) and (3.6a) in their parametrical forms, e.g.,

3.7) $F(Q,L;K_r,Kd, \quad \Theta_1,\Theta_2 \ ,\Theta_3) = 0$

so that the parameters θ_i can be estimated. These issues will be analyzed in greater detail in a later chapter.

IV) Capital-Oriented Efficiency of Large Scale Production

From the brief description in Section II (or even from the picture of diagram 2b) one can get an unmistakable impression that capital goods (i.e. the kiln design in our case) of a later vintage usually implies "large" scale operation measured in terms of output capacity or size of fixed capital investment. This impression is amply supported by the statistical data (see a later chapter) and even by casual visits on field trips. Modern technology probably implies a diminished size of firm only for a very few industries while an increasing size is the general rule. The issue of firm size is important because with the limited entrepreneurial capacity and/or the underdeveloped state of the financial market, a technology that demands a large factory may not be adopted, in spite of the efficiency of large scale production in profit terms. For these reason, the economy of scale in an industry is an important dimension of technology adoption and has been singled out for an intensive study in our approach.

Many reasons can be (and have been) given to account for the growth in size of an individual firm (e.g. to monopolize the market, to gain sense of control and for the financial advantage) which need not concern us. We must narrow down our research for the causation factor to those which are related to the engineering aspect of production. From diagram 2b) we see that a tunnel kiln must be a large one (i.e. with larger output capacity per year than the kilns of an earlier vintage) if all the "engineering principles" involved in its design are to be realized. The surface that emanates residue heat must be large and hence the kiln itself must be large. This requires special features of the furnace and internal design of the kiln for thermal control. The large kiln capacity in turn requires special engineering principles to feed the dried bricks into the kiln which has eliminated the internal loading by human hands. For example, conveyor belts that eliminate the labor needed in the sundrying process must be installed, because workers can not walk on top of the kiln. Thus a capital stock for a production technology of a modern vintage (e.g. the tunnel kiln in our case) is large and expensive primarily because it can incorporate in its design scientific principles uncovered in many diversified areas (i.e. a multitude of principles in thermal controls and mechanical devices) of science and industrial applications . The epoch of modern growth, is, after all, the "scientic epoch". (See introduction).

The above understanding is relevant to our approach (i.e. an economic analysis of technology adoptation) in a limited but important sense. For what we have just learned is that the returns to scale is determined by the size of the capital stock. For it is the capital stock (in our case, the kiln) which incorporates the scientific progress so that the economic advantage of large scale production can be traced directly to the size of the capital stock. It is this insight which must be stated as a property of the production function (1.2).

When the production function (1.2) is given, for any input point (K_o, L_o) we can define an index measuring the degree of returns of scale, by

$$4.1) \qquad s = \frac{\partial f}{\partial K} K/Q + \frac{\partial f}{\partial L} L/Q$$

To see the meaning of "s", suppose both labor and capital are increased by the common fraction λ, i.e.

4.2) a) $\lambda = dk/K - dL/L$

b) $dQ = f_k dK + f_L d_L$

c) $s = (dQ/Q)/\lambda$

When (4.2a) is substituted in (4.2b) we have 4.2c. Thus "s" is the percentage increase in output (dQ/Q) per unit percentage increase in both inputs (λ). Thus at (K_o, L_o) the production function has increasing (decreasing, or constant) returns to scale when $s > 1$ ($s < 1$ or $s = 1$). The value of s indicates the degree of returns to scale at a point (K_o, L_o). For example, when $s = 1$ everywhere, the production function is the neo-classical production function which satisfies the condition of CRTS (constant returns to scale) and (4.1) is the Euler theorem.

The abstract engineering principle that "the returns to scale is determined by the size of the capital stock" can now be interpreted as the postulation of a real postive valued function

4.3) $S = H(K)$

which specifies that "K determines s". Since H(K) can be arbitrarily specified, it can take on many forms, as illustrated in diagram 3b. In this diagram s and K are measured on the horizontal (pointing to the left) and vertical axes respectively. Three alternative shapes of the H(k) functions (aa, bb, and cc) are shown. The case of "aa" specifies CRTS everywhere. The case of "bb" is the familiar "Classical" firm which changes from IRTS ($s > 1$) to DRTS ($s < 1$) at a turning point b' ($s = 1$) as the size of the capital stock expands. The case of "cc' shows IRTS everywhere with diminishing strenth after a turning point c'. Thus (4.3) may be referred to as the scale function which describes the manner in which the returns to scale are effected by K.

When an arbitrary scale function (4.3) is postulated, a theoretical issue is "which production function (1.2) will have such a specified scale function?" Equating (4.3) and (4.1) leads to the following partial differential equation

$$(4.4) \quad H(K) = \frac{\partial f}{\partial K} K/Q + \frac{\partial f}{\partial L} L/Q$$

the solution of which

$$(4.5) \quad Q = F_H(K, L)$$

then provides the answer. If this production function is indicated by a contour map in diagram 3a and if H(K), for example, is represented by the case of "bb" in diagram 3b then all input points on the same horizontal lines (e.g. K_1K_1) will have the same value of s (e.g. $s = s_2$). Notice that a subscript "H" appears in the production function in (4.5) to remind us of the fact that the solution depends on the scale function.

Equation (4.5) represents a family of production functions, which includes as a sub-family the new classical production function (i.e. the CRTS-family) as a special case. This family may be referred to as the SSWK (scale sensitivity with repect to K) family. The family name reminds us that its derivation is based on consideration of certain abstract engineering principles discussed earlier. It is obvious that, by an entirely symmetrical precedure, we could have constructed a SSWL ("L" standing for labor) family. When Adam Smith argued for the efficiency of large scale production

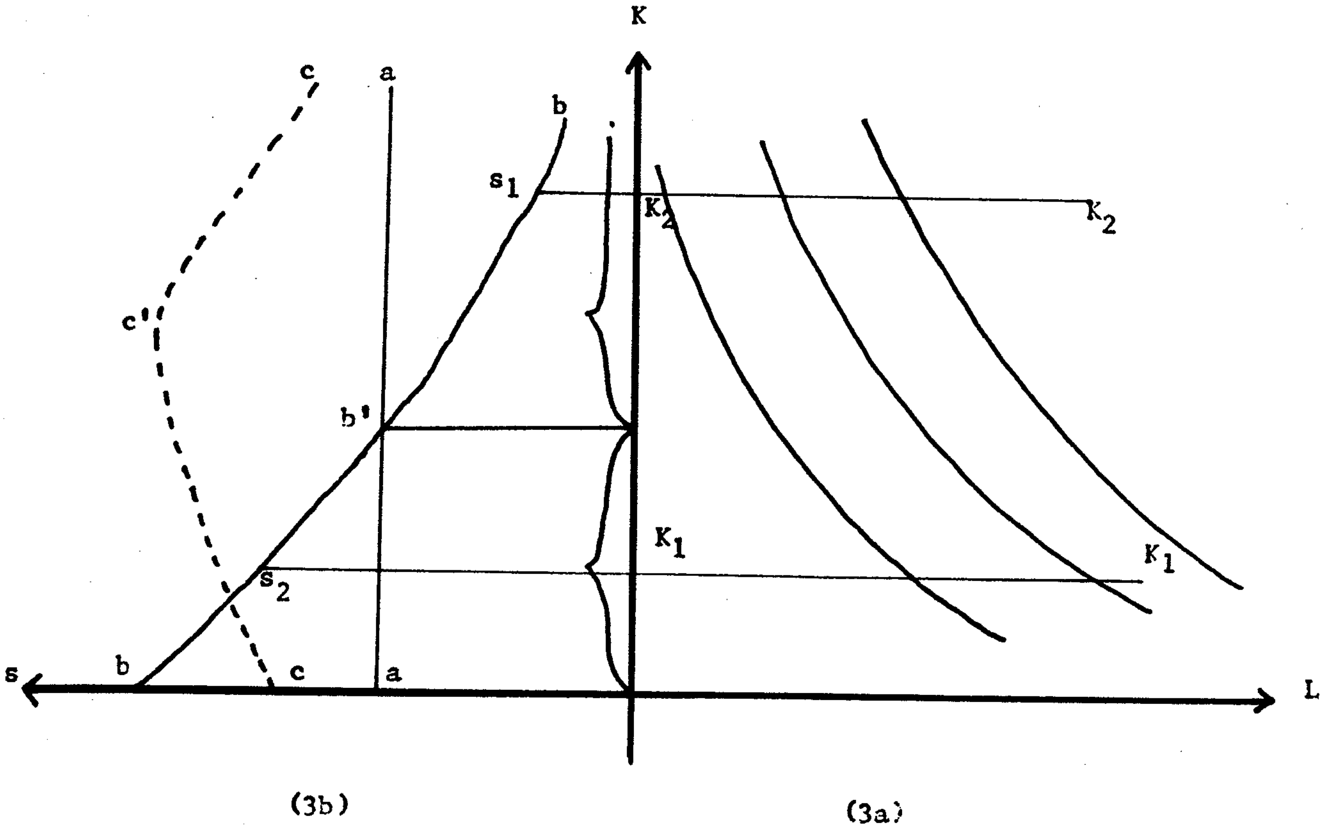


Diagram 3

based on the principle of division of labor in his well known needle factory, the relevant production function is in the SSWL family. In his case of a rural industry, Adam Smith barely mentioned the importance of incorporating innovative scientific principles into the capital equipment. Efficiency to him, is traced mainly to functional (or task) specialization brought about by the division of labor that makes use of very simple tools. The "tunnel Kiln" is a product of modern science, a far cry from the needle factory in a rural society. The SSWK family aims to catch the essence of a modern production process where scientific principles are incorporated in capital goods.

As we have discussed in the last section (section III), the comparative static analysis of technological adoption can be carried out when the production function (4.5) is restored. The meaningful issues which will be addressed in this analysis center around the technological foundation of increasing firm size through time, e.g. will the size of the firm tend to grow for a technological reason, when wage increases and/or interests rate falls. Once again, this production function (4.5) is both "realistic" and "abstract" and for the same reason (see Section III). Furthermore, again, this approach leads to theoretical, empirical and econometric researches parallel to those discussed in the last section. These matters will be treated in another chapter.

V. Scheduling Efficiency in a Step-Oriented Production Process

A modern factory is "step-oriented" in the sense that the production line is formed in sequentially ordered steps. The brick industry is simple because the production line has only four steps (S_1, S_2, S_3, S_4) which are "linearly" ordered (i.e., no "branching off". See diagram 2a). Whenever a production line is in the form of multiple steps there is always the engineering problem of production scheduling to achieve a synchronization of the various steps so that the output of one step (S_i) can move "smoothly" to the next step (S_{i+1}) as an input. In this section, we shall first discuss the abstract engineering principle of production scheduling in the brick industry. The formulation of an economic model that deals with a problem of this type will then be outlined.

Production Scheduling in Brick Manufacturing

Production scheduling is an engineering issue because it takes time to perform the production task in each step (S_i). When the production task is chemical, biological or biochemical rather than mechanical, time becomes a non-trivial issue. Production scheduling becomes a complex issue when the time t_i required at the step (S_i) varies from step to step (i.e., $t_i \neq t_j$). For then to synchronize the capacity output Q_i of S_i as inputs into S_{i+1} the time dimensions (t_i and t_{i+1}) must be calculated explicitly. (For example, if $S_i < S_{i+1}$ and if Q_i is "small" it may take several shifts in S_i to feed the one shift capacity demand for S_{i+1}). This calculation must be taken into **consideration** even at the blue-printing stage before the factory was constructed, as Q_i is determined, to a large extent, by the capital stock (K_i) installed for S_i. Hence production scheduling is an "investment" decision, rather than an operational decision, based on technological or engineering information. It is, thus, one facet of the problem of the adoption of technology.

For the brick industry the two "chemical" production steps occured at the sunning step (S_3) and the baking step (S_4)---see diagram 2a. In good weather, it takes several days (t_1) for the sun to dry the wet bricks. It takes another several days (t_2) to warm up, to bake and to cool the kiln before the next baking shift can be started. Suppose, over a unit time interval of u-days, (e.g., u = 30 days in a month), the sunning ground is to be used over n_1 times and the kiln is to be used over n_2 times (i.e., n_1 and n_2 are the number of <u>sunning shifts</u> and <u>baking shifts</u>, respectively). In case the output capacity (K_1) of the sunning ground area and the output capacity (K_2) of the kiln are to be fully utilized, the following consistency condition must be fulfilled "in the long run" for any efficiently designed factory:

5.1) a) $U = n_1 t_1 = n_2 t_2$

b) $n_1 K_1 = n_2 K_2$

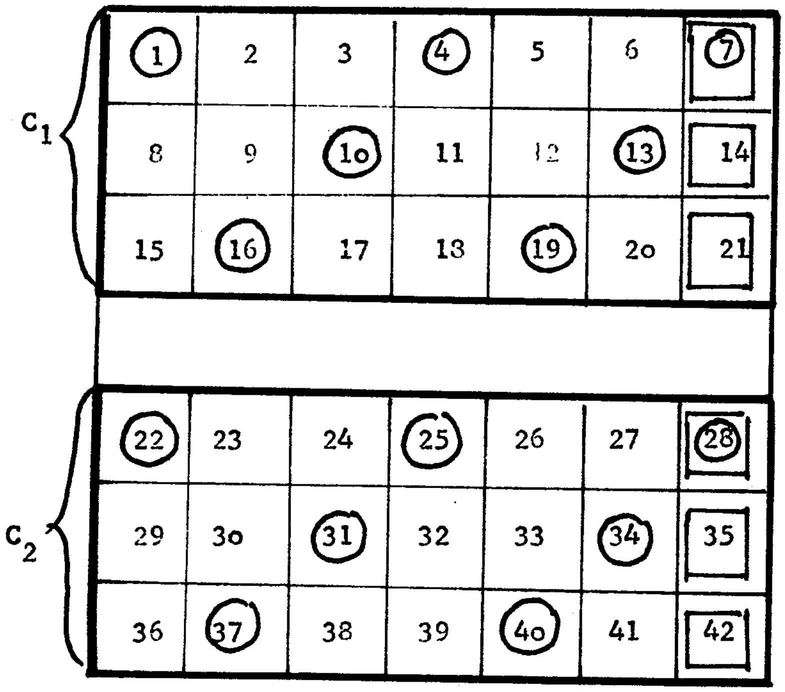
c) $K_1/K_2 = t_1/t_2 \ (= \frac{n_2}{n_1})$

Equation 5.1c states the capacity multiple (K_1/K_2) must be the same as the "time multiple" (t_1/t_2).

From our brief discussion in section II we see that two facets of the evolution of the technology in the brick industry clearly stand out as paramount. (see diagram 2b). On the one hand, the evolution from the Single kiln (VI) through the octagonal kiln (V3) is characterized, most of all, by the fact that the single gate (or compartment)---which stands for

	M	T	W	T	F	Sa	S
C_1	1	2	3	4	5	6	7
	8	9	1o	11	12	13	14
	15	16	17	18	19	2o	21
C_2	22	23	24	25	26	27	28
	29	3o	31	32	33	34	35
	36	37	38	39	4o	41	42

(4a)



weekly dried bricks			
output (1)	enter kiln (2)	(1)-(2) (3)	7oo-(2) (4)
6oo	6oo	o	1oo
6oo	6oo	o	1oo
6oo	6oo	o	1oo
9oo	7oo	2oo	o
6oo	7oo	o	o
6oo	7oo	o	o

(4b)

Diagram 4

a single baking shift--in the kiln design gave way to the multiple gate, or multiple baking shift. Intuitively, the advantage of the latter is traced to the "flexibility" in production scheduling thus gain. On the other hand, the central phenomenon in the evolution from (V3) to the tunnel kiln (V4) is the elimination of the sunning group area and the replacement of the **distinct** baking and sunning shifts (n_1,and n_2) with a continuous operation **in** production scheduling. It would thus appear that production scheduling is an important dimension of kiln design and hence of technological adaptation for the brick industry.

The simplicity of the "consistency condition" in 5.1c is deceiving, for production scheduling is an extremely complicated problem even for the "two-step" case. Some numerical examples (see Table one) will be sufficient to illustrate the complexity of the issues involved. Suppose it takes three days ($t_1=3$) to sun dry and seven days ($t_2=7$) for baking. The residue classes, modulus seven, of the positive integers are indicated by the seven columns of table 4a. As a mnemonic device, these columns are indicated as the seven days of a week. Equation 5.1a shows that the length of a production cycle, u, is a common multiple of t_1 and t_2 and hence, it is natural to choose u = 21 days, the least common multiple (LCM) of ($t_1=3$ and $t_2=7$). The"production calendar" consists of the sequentially ordered production cycles $C_1, C_2, C_3 \ldots$. The first two cycles (C_1 and C_2) are shown in table 4a and a plan for production scheduling is to be written on such a "calendar." An encircled number indicates the first day of "sun drying shift"while a blocked number indicates the first day of a"baking shift"(see table 2b).

Since a baking shift takes seven days ($t_2=7$), a necessary condition for the full utilization of the kiln capacity is that all integers in the same residue class are blocked (i.e., chosen as the first day of baking shifts). In table 4b, all Sundays are blocked. Similarly, a necessary condition for a full utilization of the sunning group area is that the encircles numbers (i.e., 1, 4, 7, 10, 13, 16, and 19) belong to the same residue class modulus, t=3. In each production cycle there are exactly $n_1 = u/t_1 = 21/3=7$ sunning shifts and $n_2 = u/t_2 = 21/7 = 3$ baking shifts, satisfying (5.1a).[1]

According to the consistency condition (5.1c), the ratio of the sunning ground capacity to the kiln capacity (K_1/K_2) must be the same as $t_1/t_2 = 3/7$. Let us then assume $K_1 = 300$ and K_2 and 700. Based on these figures, the weekly output of dried brick (i.e., bricks that are ready for the kiln) are recorded in column (1) while those that actually enter the kiln are recorded in column (2). Their difference, the dried brick which must enter the kiln not in the same week (i.e., (1) - (2)) are entered in column (3), while the unused kiln capacity (i.e., 770 - (2), is entered in column (4). It is apparent that some inefficiencies in production scheduling are involved whenever there is unused kiln capacity (i.e., positive entries in column (4)) and/or a lengthy "waiting time" is involved before the dried brick can enter the kiln (i.e., positive entries in column 3). In the example shown in (4b), the flow pattern

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[1] There is one important difference between a baking shift and a sunning shift from the engineering view point. Once a baking shift begins, the gate of the kiln is sealed and can not be opened again for at least 7 days. Once a sunning shift begins, however, wet bricks can be displayed on the sunning ground area on any day provided that there are vacancies (i.e., unused sunning ground capacity). In the examples in Table one, the problems related to underutilization of sunning group capacities are assumed to be non-existent, while, in fact, they may be important problems for a more satisfactory analysis of production scheduling.

repeats itself perpetually after the second cycle (C_2) involving both a full utilization of sunning ground and a full utilization of the kiln capacity. This is due to the fact that the consistency condition (5.1c) is satisfied.

Formally, the problem of production scheduling can be formulated as follows. Let S_i be the number of wet brick output on the i-th day (i.e., S_i bricks must enter the sunning ground in the morning of the **(i+1)th day)**. Let B_i be the number of sun dried bricks that enter the kiln on the ith day (i.e., B_i bricks begin the baking process in the morning of the ith day). Then the sunning schedule S and the baking schedule B are described by the following infinite series:

5.2a) $S = (S_1, S_2, S_3, \ldots S_i \ldots)$

b) $B = (B_1, B_2, B_3, \ldots B_i \ldots)$

The pair (S,B) is a <u>feasible production schedule</u> only if a number of engineering conditions defined in terms of t_1, t_2, K_1 and K_2 are satisfied. The kiln capacity K_2 must not be exceeded which means the non-zero entries in B can occur "at most", in a residue class of integers modulus t_2. The sunning ground capacity K_1 must not be exceeded which means that S_i must not exceed the empty space of the sunning ground on the i+1th day (a number which is, in turn, determined by the cumulative values of S_i and B_i up to the i-th day). Furthermore, S and B must be consistent in the same sense that B_i must not exceed the number of unbaked dried bricks on the i-th morning (a number which is determined by t_1 and the values of th S_i's which started the sunning process at least t_1 days earlier). All these conditions must be specified explicitly as binding conditions of an infinite linear programming problem.

It is obvious that when the engineering parameters (t_1,t_2,K_1,K_2) are specified there is a whole set F of feasible production schedules. F is the production possibility set which takes the place of the production function (1.2) for this problem. For a multiple kiln the number of engineering parameters increase; for example, when there are three compartments in a kiln the engineering parameters are $(t_1,t_2,K_1,K_2^1,K_2^2,K_2^3)$, and the feasible solution set F expands. It is thus clear that a rigorous analysis of technological adoption, depicting the evolution from the single kiln to the multiple kiln, requires an investigation of infinite programming problems of this type.

Technology Adoption

With the knowledge of factor and product prices one can choose a feasible production schedule from F that maximizes profit. Suppose the profit maximizing production schedule (i.e., the maximum feasible solution) is

$$5.3) \qquad (S_o,B_o) = U(t_1,t_2,K_1,K_2^1,K_2^2,K_2^3,,w,p,i)$$

which is seen to be a function of the engineering parameters as well as the wage rate "w" the price of bricks "p" and the interest rate "i". (The economic interpretation of such a maximizing problem is the "minimization of working capital cost" because the problem involves dated input and output.) In this form, technology adoption becomes a parametric linear programming problem. For example, with an increase in wage rate "w" and a lowering of the interest rate "i", the "evolution" from a single kiln to a multiple kiln appears as properties of the maximum feasible solutions (S_o, B_o).

It is apparent that comparative static theorems are quite difficult--as all parametric linear programming problems are difficult to solve. For example, the problem can be very complicated when the uncertainty of weather is taken into consideration, as t_1, the "sunning time", must be described by a probability function. Thus the preliminary work in a later chapter on this subject merely serves to indicate the intricacy of the analytical issues involved in the problem of production scheduling, and recognizes that we are nowhere near a "general solution." Yet, such a beginning must be attempted as production scheduling appears to be a major dimension of technological evolution in the brick industry.

VI) Conclusions

An engineering oriented approach to the adoption of technology is based on the belief that the epoch of modern growth is a scientific and engineering epoch and hence the adoption of "engineering principals," as controlled by market prices, lies at the heart of technology change. The blending of the "engineering principles" and "economic models" in our approach emphasizes that technological evolution is a rational historical process.

The three "abstract" engineering principles which we discussed in the sections III, IV and V have, by no means, exhausted all the engineering principles involved, even for such a simple industry like brick manufacture, which is literally the product of many many areas of scientific progress. The three principles are singled out because they appear to be essential for brick manufacturing and more importantly, for some other industries as well. While concentrating on bricks, we hope that our method of analysis, involving theory and statistical data, is transferable.

We will not attempt to duplicate the task of the engineers by integrating the three principles into an all-inclusive framework for the brick industry. We the economists will "cut up" the brick industry into "parts" and look at the three engineering principles individually and separately. Our hypothesis singles out these three principles, a priori, as "relevant." An assessment of which of these principles are dominant, essential, or irrelevent, for technology adoption is the primary aim of empirical research based on sample return data for the shoe industry.

Ordinarily when people look for the policy implication of a theory on technology change they address a set of issues vaguely related to economic agents (e.g. how to promote the growth of the entrepreneurship in a particular cultural meliu, and how to design an education system to supply the skilled man power); the discovery of the technical information (e.g., R and D expenditures, the patent right laws or dissemination of technology through conference; and institutional organization (e.g., the imperfection of the product, the inputs, and the financial markets). The readers will, of course, search in vain in our report for this type of policy recommendation --for the simple reason that these issues are neglected by our assumptions of perfect market, perfect entrepreneurship and free information (see introduction).

There are policy implications in our approach which will be summarized in the last chapter. Nevertheless, in anticipation of criticisms of our report as esoteric and irrelevant, we must add that this is a very embryonic stage of our knowledge of technology change. The primary purpose of initial research is to mark off phenomena which are essential from non-essential and relevant from irrelevant. For the scientific epoch of modern growth, **our hypothesis is** that an engineering oriented approach is essential and relevant. The thesis, whether supported or even rejected by data, will contribute to the primary purpose of initial research. We believe that healthy policy in the long run depends upon initial research of this type.