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AGRICULTURAL AND FACTORY PROCESSES: IMPLICATIONS FOR EMPIRICAL RESEARCH*

Casual observation suggests that there are more (reported) studies of production analysis that deal with agriculture than production studies dealing with any other sector of the economy.¹ If this observation is correct, the explanation of the phenomenon may well be randomness: it may be purely accidental that researchers most commonly dip into data from agriculture to fit production functions. An alternative systematic explanation is that the body of knowledge commonly called the neoclassical theory of production is better suited for the study of agricultural economics than it is for other fields of economics.

These random thoughts found encouragement in some recent writings by Nicholas Georgescu-Roegen (5, 6, 7). In his familiar lucid style and with his penchant for forceful advocacy, Georgescu-Roegen has suggested a number of provocative ideas that bear on the special applicability of the production function as a tool for agricultural economics research. These ideas will serve here as a springboard to reach conclusions about the empirical implications of the specification of the production function for agricultural processes.

THE CHARACTERISTICS OF AGRICULTURAL AND FACTORY PROCESSES

One crucial distinction between factory and agricultural processes lies in the choice of the *initiation date*. The former can be started at any time (or "in line"). The latter have to be started at specified dates within the annual climatic cycle (or two duplicate agricultural processes have to be started simultaneously, i.e., "in parallel"). Exceptions of course exist—such as broiler farms, cattle feeding, or rice production in Indonesia.² But these exceptions and others will be overlooked for the sake of analytical convenience.

The second distinction refers to the possibilities that exist for temporal forward *substitutability* of the factors of production in factory and in agricultural processes. Labor at plowing time is not generally substitutable for labor at harvesting time.³ Nor are capital inputs forward substitutable in general. As a result agricultural processes impose some inevitable idleness on capital and labor

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¹ For summaries of the results of different production studies, see A. A. Walters (11), E. O. Heady and J. L. Dillon (9), and P. A. Yotopoulos (13).

² Nevertheless, lambs are born in spring and eel and snake meat is best to eat in late fall.

³ One can think of double-cropping as an exception. The operative word is "generally."

over the production period and complete idleness over the rest of the year (5, p. 525). In factory processes idleness is not inevitable. A painter's brush can be continuously substituted for higher-timed inputs. A table can be painted one, two, or n days after it is planed. A sufficient number of tables can be started in line so that different operations dovetail together and the idleness of some arbitrary stock input is minimal. The paint can be bought all at once or in smaller quantities as it is to be used in the period of production. Together with division of labor, it is this lack of temporal specialization of the inputs of production that makes factory processes "cheap."⁴

The corollary of substitutability is compressibility of the period of production. Perfect forward substitutability implies that the period of production can be compressed toward zero. After a certain point, i.e., once there are *goods in process*, we can have only output and no more inputs, if we continuously substitute lower-timed inputs for higher-timed inputs. In practice, however, the compressibility of the period of production manifests itself in the simultaneity of input and output flows.

A number of operational differences in empirical work on production functions derive from the difference between factory processes and agricultural processes. First, in agricultural processes there exists a natural period of observation and analysis—the annual cycle. Second, the inevitability of idleness of stock inputs in agricultural processes makes, *ceteris paribus*, over-mechanization in agriculture more expensive relative to over-mechanization in industry, the higher the rate of interest is. Suppose the marginal product per unit of service of an agricultural machine is equal to the marginal product per unit of service of a factory machine and that each machine will last ten years. To the extent, however, that the latter machine will be fully employed each year while the former will produce services for only part of the year, the effective price of services rendered of the agricultural machine will be higher than the effective price of services rendered of the factory machine.⁵ Georgescu-Roegen remarks that ". . . if income is low [or if the rate of interest is high], as is the rule in over-populated countries, heavy machinery is a luxury comparable to that of a splendid villa on the Riviera used for a couple of weeks each year" (5, p. 526). In the same country, however, a modern, capital-intensive steel mill may be a good investment. Third, goods in process should be explicitly introduced in a function that describes factory processes. Fourth, because of the compressibility of the period of production, the length of the working day should be explicitly introduced as an independent variable in the description of production of factory processes. Moreover, it is easier to increase the length of the working day in industry without running into severe diseconomies of scale than it is in agriculture. (There is not much that the graveyard shift could contribute to agricultural production.) This may

⁴ Division of labor, it should be noted, comes at the cost of idleness when processes can start only in parallel. As a result we are more likely to find in agriculture the same laborer pruning, thinning, spraying, irrigating, and helping harvest a fruit crop. It is cheaper for the Maoist man to come from the farm than from the factory.

⁵ This statement should be qualified. To the extent that maintenance and frequency of repairs are functions of the rate of use, the relative price per unit of service of the agricultural machine decreases. Still, however, the price per unit of service in the two uses will not be equal, as long as obsolescence is not a function of the rate of utilization, i.e., as long as the useful lifetime of each machine is ten years, with no regard to its rate of utilization.

be part of the reason why institutional arrangements (through the labor unions) to limit the length of the work day and to control overtime work first appeared in industry and not in agriculture.

MAINTENANCE AS THE LINK BETWEEN FLOW INPUTS AND FUND INPUTS

Another important difference between the production function of agricultural and factory processes derives from the fact that the inputs of agricultural processes are timed.⁶ I will first follow Georgescu-Roegen (with modifications) in describing a simple agricultural process, that of producing corn by a method requiring only a hoe for preparing the ground, with the other operations being done by hand. Subsequently I will introduce a slight complication.

The following tabulation describes what "enters" and what "exits" from this agricultural process in a period of time T .

Enter	Exit	
Ricardian land, one acre	Ricardian land, one acre	$L(t)$
Laborers, one rested man	Laborers, one tired man	$H(t)$
Hoes, one new	Hoes, one used	$K(t)$
Seed, one bag	None	$I(t)$
Fertilizer, one bag	None	$I(t)$
	Corn, 11 bags	$O(t)$

A conceptually unambiguous approach would be to describe the production function as the mapping of the "inputs" on the enter side into the "outputs" of the exit side. However, at the present state of development of the tools of the joint-product production function this approach is not feasible.

Georgescu-Roegen follows another approach. Some elements in the above process appear only on the exit side. Call corn *output*, $O(t)$. Some other elements figure only on the enter side. Call these *flow inputs*. The problem arises with the elements that appear both on the enter and the exit side. One can invent another flow artifice and call it *maintenance*, $M(t)$. Maintenance is defined as something that, added to the exit side of these latter elements, gives the enter side. After considering $M(t)$, the exit side of these elements should be identical with their enter side. These elements are defined as *fund inputs*, i.e., as a particular kind of stock which enters and comes out of the production process in an economically, if not also physically, identical form and in the same amount—i.e., it remains constant in size. Then the production function is written as a functional mapping:

$$O(T) = G[I(t), M(t); L(t), K(t), H(t)] \quad (1)$$

with inputs separated as flow inputs and fund inputs.

The mapping in equation (1) is a formalistic statement which, although conceptually clear, is empirically inapplicable. An operational approach is to focus on aspects other than time shapes of inputs and output and to write equation (1) as a monopерiodic production function. To demonstrate the problems with equation (1) consider two complications. Instead of hoes we now have a tractor. Instead of corn we produce apples and for this purpose we have apple trees. The mapping appears in the following tabulation.

⁶ For a discussion of momentary versus time-shaped production functions, see 4, Chap. 4.

Enter	Exit
Ricardian land, one acre	Ricardian land, one acre
Laborers, one rested man	Laborers, one tired man
Tractor, one new	Tractor, one, one year old
Fertilizer, one bag	None
Gasoline, 15 gallons	None
Apple trees, 50, 10 years old	Apple trees, 50, 11 years old
	Apples, 500 bushels

How does one account for the "maintenance" artifice that, added to the 11-year-old apple trees on the exit side, transforms them to 10-year-old apple trees on the enter side?

Before we return to the two specific examples of the process of production it is worth remembering the Fisherian distinction between stocks and flows (3). Stock relates to a point in time; flow to a stretch of time. Can we then look at two successive points of time to infer what happened in between? Fisher's answer is yes. It happens to be correct in a mechanistic view of the world where any event in a phenomenal domain is the result of locomotion alone. From the observation of zero miles on the odometer at t_0 and 60 miles at t_1 , an hour later, I infer that what happened in the stretch of time is: $(60 \text{ miles} - 0 \text{ miles}) \div (1 \text{ hour})$, i.e., velocity of 60 miles an hour. I will utilize Georgescu-Roegen's view of the application of the Entropy Law in economic processes to challenge Fisher's view of classical mechanics. I will argue that in social processes such as economic production there has also been a qualitative change between t_0 and t_1 which does not allow us to infer what happened in the period by merely observing the two end points. More specifically we can reconstruct the process only by knowing, or by assuming, something about the economic glue that keeps together the points of time and the stretch of time. It is the *service flow*.

FROM STOCK INPUTS TO FLOW INPUTS THROUGH THE THEORY OF CAPITAL

We may now return to the two illustrative tables of the process of production and the problem of mapping of inputs and outputs. Instead of distinguishing flow inputs and fund inputs, as Georgescu-Roegen suggests, I will advocate a mapping that considers service flows of inputs per period of production as argument in the production function. This will necessitate grouping of the inputs in the two examples above into four distinct groups: first, seed, fertilizer, and gasoline, and also labor by convention; second, land; third, tractor, hoe, and labor conceptually, although not empirically; and fourth, apple trees.

The characteristic of the first group is that the service flow is defined as the difference between the enter and the exit side. Seed, fertilizer, and gasoline are current inputs. So is labor if it is defined in terms of man-days devoted to production, or in terms of the wage rate that compensates for their toil. This is the usual statistical convention that writes labor only in the enter side and skips the mention of one tired man in the exit side.

The rest of the groups cannot be handled in such a simple manner because there may have been some change (quantitative or qualitative) between the enter and the exit side. This change is partly a physical phenomenon and partly a market phenomenon.

A stock input deteriorates while it is involved in the process of production as a result of aging and use. *Deterioration* represents the decrease in the efficiency of a machine that will be reflected in rising operating or maintenance costs with each successive period of production, in expense due to time lost, or, simply, in less output per unit of time. Deterioration definitely affects the services that the capital asset delivers in the period of production.

Over and above the quality of services that an asset delivers in the process of production, and independently of it, another change has occurred between the enter and the exit side. The asset is older by one unit of time. *Exhaustion* is the differential (penalty or bonus) that is attached to the fact that there is one less year of life left in the asset and the configuration of future service streams will no longer be the same. We are closer to the last year that makes the difference between asset and no asset or laborer and no laborer. The proximity to the finish line *per se* (as distinguished from deterioration) does not affect the services that the asset delivers in the process of production. But it affects the view that the marketplace takes of the asset. Last, *obsolescence* is the penalty that is attached to old machines because of the probability of better machines becoming available.

At the exit side, then, we observe an asset that has had three things happen to it: deterioration, exhaustion, and obsolescence. Following Georgescu-Roegen's application, the asset has higher entropy—i.e., more of its energy is "bound" than it was at the enter side. Part of the qualitative change that followed the Entropy Law has affected the way the asset performed during the period of production we observed; part of it has not. The former must be accounted for in the production function; the latter must be excluded. We can now proceed with the handling of the other three groups among the original four groups of factors that we distinguished.

Ricardian land (i.e., "inexhaustible land") enters the production process, yields services, and exits intact. It is, in Georgescu-Roegen's terminology, a truly fund input in the sense that it remains constant in size *and it lasts forever*. Under these convenient assumptions the fund of land is related to the services of land by a constant factor of proportionality (e.g., $R = V/r$, where V is the "value" of land and r the rate of discount). In a multiplicative production function it makes no difference whether we use acres or any other stock concept as a proxy for services. We can hardly misspecify the land input.

The third group, in the example of the tractor (and hoes, as well as labor, if there were a market for human beings), is another story. It is a *stock input*, not a fund input, in the sense that its "size" does not remain constant between year zero and year one of age. Three things happened to the tractor between the enter and the exit side: it deteriorated (i.e., its capacity to supply current services has decreased); it was partially exhausted (i.e., it now has one less year of life left); and it became more obsolete (i.e., it has to coexist with better machines that are becoming available). The *stock* of the tractor that the market measures at the exit side takes into account all three factors, deterioration, exhaustion, and obsolescence. The *service flow*, however, that the tractor contributed as an input of production should allow only for the deterioration factor. Exhaustion and obsolescence are market phenomena and as such irrelevant for the purposes of the theory of production. How can we separate the irrelevant market phenomena

from the relevant physical deterioration by using information that can be easily obtained in the real world? For the case of the tractor it is easy to derive a service flow formula based on an annuity principle and the original purchase price, either under the "one-hoss-shay" assumption (i.e., stock variable but service flow constant to the end of the tractor's life) or under an assumption of a constant rate for service flow deterioration (12).

The one-hoss-shay assumption, as applied to mechanical assets, implies that the productivity of these assets does not change (deteriorate or improve) with age until retirement. Therefore an asset that falls in this category is expected to yield a regular, i.e., a rectangularly distributed, stream of services until it is retired at a pre-known date (and at a zero value for convenience). Then, under an equilibrium assumption, the original market value of the asset is the capitalization of this regular service stream, given the configuration of the expected future output prices. Using continuous discounting, this is written:

$$V_o^T = \int_0^T R e^{-rt} dt, \quad (2)$$

where V_o is the original value of capital asset, T is its life expectancy, R is the annual service flow from it, and r is the appropriate rate of discount.⁷ By the assumption of regular service streams ($R = f(t) = \bar{R}$) and assuming a constant rate of discount, equation (2) can be written, solving for \bar{R} :

$$\bar{R} = \frac{rV_o^T}{1 - e^{-rT}}. \quad (3)$$

Equation (3) is an annuity formulation of the service flow for an asset. It is free from deterioration, since the annual service flow was assumed to be regular. It does not include exhaustion, since it is derived from the gross capital stock as represented by the original market value of the asset. It also overlooks obsolescence by keeping the expectation function of relative output prices constant. The series of $R(t)$ is actually Keynes's "prospective yield." It consists of the annual receipts derived from an asset over its lifetime, after deducting the running expenses but not deducting depreciation (which is the contribution to the replacement fund of the asset, or what I called exhaustion) (10, p. 135; 8, pp. 121-24).

For positive rates of discount the annual service flow is always non-negative, and as T tends to infinity it reduces to a rate of discount multiple of the original asset value. This is the case of land, as already mentioned. However, it is not unlikely that the current service flow will take on negative values under certain circumstances. This is the case of the fourth category of inputs, apple trees.

Apple trees (and animals) and, in general, machines that involve a learning period for optimum operation (2) present a more complicated case. For a period in their lifetime their service streams improve with age (negative deterioration at an unknown rate) in the sense that they get closer to their peak maturity and maximum output rate. Thereafter their service streams deteriorate with age (again at an unknown rate). How can we measure from observable market

⁷ The formula can be rewritten for an assumed constant rate of deterioration, s , as:

$$V_o^T = \int_0^T R e^{-(r+s)t} dt.$$

phenomena this service flow, again free of exhaustion and obsolescence, to use as an input of production?

We may no longer safely assume a constant service stream when apple trees (and animals) are concerned. One would rather expect that the current service flow of live capital assets is first an increasing and later a decreasing function of the asset's age. Eventually, one may reasonably suppose, the service flow reaches zero on the date of the asset's retirement. Our computational procedure should recognize this feature.

Had we known *a priori* the form of the stream function (even up to a proportionality factor) we could have derived $R(t)$ from the original asset market value by postulating the rate of discount. The procedure would have been in principle the one used for the third kind of assets. This information, however, may not exist. Therefore, we have to derive the irregular service stream function from the available information about the market value function. These data consist of current market value observations for each asset; they comprise the market devaluation net capital concept.⁸

I have already indicated that the current market value of an asset, being the capitalization of all expected present and future service streams, embodies all three factors: deterioration, exhaustion, and obsolescence. Lacking information on the secular behavior of output prices, we may in this case also assume the configuration of future output prices to be constant; i.e., we suppose that the obsolescence factor is trivial and may safely be overlooked. Deterioration and exhaustion, on the other hand, play an important role.

To simplify (probably with no loss of realism), assume that the service flow of trees is an increasing and, eventually, a decreasing function of age with one maximum value at the point that we define as full maturity age. In a perfect market we would expect the net rental of the asset to be increasing up to the full maturity age and decreasing thereafter. This certainly should be reflected in the capital input concept that enters the production function. It is the service flow deterioration factor that is first negative (i.e., represents amelioration or improvement of the asset with age) and then positive. We would not, however, necessarily expect the current market value function to have a maximum at the same age that the maximum of the service stream function occurs because of the exhaustion factor.

Exhaustion is the differential that the market attaches to the change in the configuration of the future service streams. The shape of this service stream distribution now presents two pivotal points: the known life-length of the asset and its age at full maturity. As we move from one net capital value to the next, we get closer to the end of the asset's life—which elicits a penalty from the marketplace. The same move, however, brings us closer to, or further away from, the full maturity age. If the latter happens, i.e., if the asset has passed the maximum value of its service stream, the market also attaches a penalty. However, if the converse is true, the impatience factor attaches a premium to the fact that the asset is closer to yielding its maximum current service flow. Thus, exhaustion will both boost and dampen the current market value as long as we operate on

⁸ The rest of this section follows closely my exposition in 12 and 13.

the increasing section of the service stream function. When the difference between the premium and the penalty reaches a maximum value, the peak of the market value function will also occur. The purpose of the identification of the exhaustion factor is to exclude it from the capital input formulation. The reason for this is that exhaustion refers to the market's valuation of the expected *future* services of capital. Production function analysis, on the other hand, is concerned with the available *current* flow of productive services. We are therefore faced with the problem of devising a way to exclude the exhaustion factor from the present service flow formulation, while including the deterioration (amelioration) factor.

The relation between the current market value V_t (i.e., the market-devaluated net capital stock) of an asset in the t year of its life and its current service flow R_t (for $t = 1$ to T , where T is the retirement age of the asset) may be expressed as follows, if we assume perfect markets (and writing for the discount factor $d = 1/[1 + r]$):

$$\begin{aligned} V_1 &= R_1d + R_2d^2 + R_3d^3 + \dots + R_Td^T \\ V_2 &= 0 + R_2d + R_3d^2 + \dots + R_Td^{T-1} \\ &\dots\dots\dots \\ V_T &= 0 + 0 + 0 + \dots + R_Td^1 \end{aligned} \quad (5)$$

The general term of this power series, solved for R_t , is:

$$R_t = rV_t - (V_{t+1} - V_t). \quad (6)$$

What is the interpretation of the current service flow function in equation (6)? The term in parentheses represents the change in the market evaluation of the asset between two consecutive periods (i.e., the difference between two succeeding capital stocks). Start from the case that this term is zero for all time subscripts (the net capital stock does not change with time). This implies that the asset is inexhaustible (like land) and that the current service flow is proportional to the capital stock, as the first term on the right-hand side of equation (6) shows. If the term in parentheses is positive, this indicates that the asset appreciates between two periods. In this event, however, the first term alone of equation (6) overestimates the current service flow, since the net capital value V_t is biased by the impatience factor that has attached a premium to it by reason of getting closer to the asset's full maturity age. This has been explained already. Thus, in the case of appreciating assets the subtraction of the corrective positive term in parentheses expresses the current service flow free from the operation of the exhaustion factor. The converse is true of depreciating assets. The first term of the equation is increased by subtracting the negative term in parentheses in order to express the current service flow corrected for the penalty that exhaustion has placed on the asset's current net capital value because of its having moved away from the full maturity age and closer to the retirement age of the asset. Thus equation (6) is interpreted as expressing the current service flow as a function of the asset's current market value, after correction for the exhaustion factor which is included in the market value. As with regular service streams R_t represents "the prospective yield" of an asset. It is the annual receipts derived from the asset after deducting the running expenses but without including exhaustion.

SUMMARY AND CONCLUSIONS

The motivation for this paper was to emphasize the features that distinguish agricultural and factory processes and to explore the implications that these features might have for empirical research on production analysis. The existence of a natural period of observation and the non-compressibility of the period of production that refer to agricultural processes are reflected in empirical work in terms of the time element in the production function and the simplification of the treatment of goods in process. Moreover, land, which is a crucial input in agriculture, facilitates the conceptually difficult problem of going from stocks to flows for the purposes of empirical research. I gave special emphasis to this last feature.

The problem of mapping of monopерiodic (i.e., flow) and multiperiodic (i.e., stock) inputs into output is germane in the analysis of production. It can be solved in a conceptually consistent manner by converting stock inputs into flow inputs. Agricultural production that significantly involves land represents many advantages over factory production when this mapping is concerned. Land is truly a "fund" input: it enters and exits the production process, and it remains unchanged. As a result, it is a most convenient input for econometric research. After minor adjustments for quality, for irrigation, and other improvements, it can be easily (and correctly) specified in a number of ways—as acres, as land rent, and so on.

In summary, the preceding analysis tempts one to accept the systematic explanation for the plethora of fitted agricultural production functions: that it is easier to apply neoclassical production analysis in agriculture.

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