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WHAT IS PRODUCTIVITY: CAPACITY OR WELFARE MANAGEMENT?

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ABSTRACT

A number of recent papers have examined the role of environmental variables in accounting for economic growth, and have concluded that net measures of national product are superior to gross measures in portraying the outcome of the growth process. This paper argues that the two measures are not substitutes, but complements which reveal different aspects of economic growth: gross product is the output concept for estimating the structure of production, while net product is the correct concept for getting at the welfare consequences of economic growth. It is then shown that this capacity-welfare nexus is mirrored in the Hicksian and Harrodian definitions of technical change. An alternative to the conventional Solow growth accounting framework is presented in which the change in national wealth is decomposed into components corresponding to labor input and the Harrodian rate of technical change.

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Economists have studied the wealth of nations since the time of Adam Smith, but serious empirical work had to await the development of comprehensive data on national income and wealth. An ideal set of national accounts provides information on the extent and composition of a country's economic activity, and if this information is consistent over time, an analyst can track the growth of national output and wealth. In practice, however, there are many difficulties. Quite a few of the most important variables are hard to measure, and the national income accountant is often limited to collecting only those data generated by market transactions.

Unfortunately, the economics profession has not invested heavily in solving these data problems. Asking an economic theorist to worry about data is, it seems, like asking a great chef to grind his own flour. However, ingredients do matter, in economics as well as cooking, and the failure to measure all resource costs accurately can lead to a distorted picture of economic growth: for example, a society which grows by using up its environmental capital does so by sacrificing future consumption, and will end up being worse off in the long run than another society that achieves the same rate of output growth by building up its capital and investing in technology. Fortunately, the growing concern over the deterioration of the environment has spilled over into accounting area, and recent papers by Hartwick (1990) and Mähler (1991) have demonstrated how the accounts can be extended to incorporate an explicit nonmarket component.

This interest in "environmentally correct" accounting procedures has also lead to a renewed interest in the old debate over the right measure of output for the purpose of analyzing the sources of economic growth. In their seminal contributions, both Solow (1957) and Denison (1962) proposed output net of depreciation as the appropriate concept of national product, on the grounds that increases in gross output might be generated solely by a more rapid consumption of the stock of capital. This proposal was reinforced by the work of Weitzman (1976), who showed that the net concept was related to an economy's maximum attainable wealth. But, another important article by Jorgenson and Griliches (1967) argued that gross output was, in fact, more relevant for tracking the supply-side constraints that limit the process of growth. Most of the recent literature on production and growth has accepted this point of view and has used gross output as the appropriate measure of economic performance.

However, it turns out that the net and gross concepts of output really are not competitors for the role of the "correct" measure of national product. Instead, each provides the right answer to a different question. Net measures of national product are appropriate for measuring the economic welfare associated with a given program of growth, but it is gross output (GNP or GDP) that is the right concept for measuring the volume of national output, and for estimating changes in the productive efficiency of the economy. As long as these two questions are not confused - and they often are - both measures of national economic performance provide important insights into the process of economic growth (and, by extension, it is wrong to argue that net national product should replace GDP in national accounting frameworks). Moreover, a parallel confusion exists over the appropriate concepts of technical change, and it turns out that the two major alternatives - the Hicks and Harrod definitions - are really not competitors after all. They are, like gross and net output, the relevant concepts for measuring the respective changes in capacity and welfare (or, more accurately, wealth).

These themes are developed in the following pages of this essay. We will first examine the "net versus gross" issue in the context of a simple model of economic choice, and then go on to sketch the link between growth accounting and the Hicksian and Harrodian measures of technical change. The final pages illustrate some of the pitfalls that await anyone who tries to obtain a perfectly clean separation of capacity and welfare measures of economic performance.

I. Accounting for Welfare and Capacity Growth

A. The World of Robinson Crusoe

The number of ways to design an internally consistent set of national accounts is limited only by the imagination. It is possible, for example, to build one set of accounts around the net output concept of national product, and another set around gross output. As a result, accounting theory *per se* gives little guidance on which output concept is appropriate for what purpose. What is needed, instead, is an economic model to act as a paradigm for the accounts. In this way, the accounting definitions and identities follow from the model in such a way that the underlying economic structure can be retrieved by the economic analyst. This requirement is of critical importance for accounting practice, since it places strong consistency restrictions on the procedures used to construct the national accounts.

The duality of economic and accounting frameworks has been exploited by Hartwick and Mähler to derive the accounting principles associated with some very sophisticated models of intertemporal economic choice. We, too, will follow this path using the far simpler, but nonetheless informative, "Robinson Crusoe" model. This is a model in which there is a single output (which we will call "corn") and a single consumer-producer (Robinson). Robinson is shipwrecked on a tropical island, and salvages an endowment of corn from the wreck before it sinks. This initial endowment of corn can be consumed or planted as seed-corn to obtain a crop in the following year. The method of producing corn is summarized by a production function which indicates that the maximum output of corn that can be produced in any year depends on the amount of corn-capital that is planted, and on the amount of work that Robinson is willing to do.[1] A shift term also included in the production function to allow for the possibility that technological progress leads to more efficient corn production over time.

Once the corn is produced, the output is divided between consumption and investment: consumption increases Robinson's immediate felicity, while investment is adds to future happiness by increasing the seed-corn available for production in the following year. For simplicity, we start by assuming

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[1] In the formal notation of production theory, this function can be written as $Q_t = F(K_{t-1}, L_t, t)$. Capital stocks are lagged one year to conform to the convention that the capital available at the start of the year determines the flow of services from the stock.

that a fixed percent of the seed corn is lost (depreciated) in each year that it is planted, so that the net change in corn-capital is equal to gross investment less the capital used up in production.[2]

Robinson's problem is to choose how much output to consume now, and how much to set aside to increase his consumption in the future. The nature of this choice is shown in Figure 1, for the simplified situation in which Robinson lives for only two years: the curve $\mathcal{AB}$ shows all the combinations of consumption in years 0 and 1 that can be attained given the amount of corn rescued from the ship, the technology for producing corn, and the amount of work effort. If Robinson consumes all the corn brought from his ship, none can be used for planting and next year's consumption is zero. This is the point $\mathcal{A}$. If, on the other hand, all of the initial endowment of corn is planted, $\mathcal{OB}$ units can be consumed in the following year. Robinson's actual choice is determined by his preference for consuming corn in the two years, which we represent by a choice function with makes total (ordinal) utility the sum of the annual utilities derived from consumption in each year:

$$U_0 = \sum_{t=0}^{\infty} \rho^t \, U(C_t) \qquad (0 < \rho < 1) \ . \tag{1}$$

This is the so-called "Ramsey Intertemporal Utility Function" in which annual

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[2] If δ is the rate at which the corn-stock depreciates, the capital available for production in the following period is equal to $K_1 = I_1 + (1-\delta)K_0$.

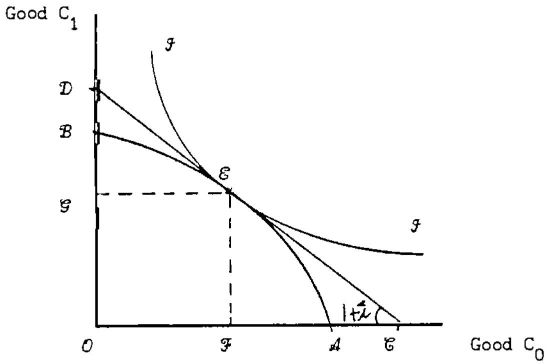

Figure 1

utilities are given a decreasing weight over time to account for the greater felicity attached to corn consumed now relative to corn consumed in the future. We will assume, for simplicity, that Robinson has rigid work habits and devotes a fixed number of hours a year to growing corn, so this formulation of the utility function ignores the choice between working and leisure (but, this is a complication that can be easily remedied by expanding to the utility function to include a leisure variable).

A rational Robinson will arrange his consumption so as to maximize his utility. This occurs at the point $\mathcal{E}$ in Figure 1, where the utility function is tangent to the production possibility frontier $\mathcal{AB}$. At this point, Robinson chooses to consume $\mathcal{F}$ units of his initial endowment, and uses the rest for planting. Since there is "no tomorrow" after year 1, the entire output of this year is given over to consumption. However, when there are

TABLE 1

(1) YEAR	(2) LABOR INPUT	(3) CAPITAL INPUT	(4) OUTPUT	(5) INVEST-MENT	(6) CONS-UMPTION	(7) WAGE	(8) GROSS RETURN	(9) NET RETURN
1	1	100	50	10	40	37.5	0.125	0.025
2	1	100	50	10	40	37.5	0.125	0.025
3	1	100	50	10	40	37.5	0.125	0.025
4	1	100	50	10	40	37.5	0.125	0.025
5	1	100	50	10	40	37.5	0.125	0.025

TABLE 2

(1) YEAR	(2) WEALTH	(3) GROSS INCOME	(4) DEPREC-IATION	(5) NET INCOME	(6) HAIG-SIMONS	(7) NET PRODUCT
1	1600	50	10	40	40	40
2	1600	50	10	40	40	40
3	1600	50	10	40	40	40
4	1600	50	10	40	40	40
5	1600	50	10	40	40	40

multiple years to consider, part of the year 1 output is saved and added to the corn-stock for the following year. This process rolls on year after year, and Robinson's optimal consumption path may even settle into a steady-state in which one year looks just like the next.

This last possibility is portrayed in Table 1 for a five year time span. Each row gives all the annual statistics on the amount of labor input (one, since Robinson is the only works and he gives a fixed amount of his time to production), the stock of corn capital available for planting (100 bushels), and the resulting output (50 bushels). We have assumed that Robinson's utility function is such that a constant fraction of output is saved, so that output is divided between consumption and investment in a constant proportion (40 and 10 units). This amount of investment is just sufficient to replace the corn that is lost (depreciated) during planting, so the economy remains at the same allocation of resources from year to year. The wage and gross return to capital also remain constant.

B. Robinson the Accountant

Robinson may want to set up an accounting framework to monitor the success of his "economy." In so doing, Robinson the Accountant must confront the following issue: what does he want his accounts to tell him about the economy? Should he focus on annual changes in his production levels, or on the amount of consumption, or on the stock of corn available at the end of each year? Should he measure his success relative to his ability to produce corn efficiently, or relative to the welfare he derives from the production of corn.

The answer is a qualified "all of the above". A complete set accounts should tell Robinson (and anyone else) about the factors that lead him to his optimal consumption point $\mathcal{E}$ in Figure 1. This, in turn, comprises two sets of factors: those determining the position of the production possibility frontier $\mathcal{AB}$, and those associated with the choice of the optimal point on the production possibility frontier. The first set of factors involves the capacity constraints implied by the production function and initial endowment of capital, while the second set involves the utility function and the associated amount of wealth from equation (1).

The basic rule for putting together the capacity side of the accounts is that the information collected should permit the user to retrieve the "law" by which input is transformed into output. Robinson the Accountant might pause to wonder (as have many other national income accountants and growth analysts) whether this "law" involves a measure of output which is net of the corn-capital used up in production, but two arguments persuade him that the gross amount of corn production is the right concept for the capacity side of his accounts. First, as a farmer, he wants to know the size of his harvest - the total number of bushels that he was able to grow. This gross size of the harvest is the same whether or not 10 or 20 bushels of corn-capital are used up.[3] Second, when it comes time to decide on how much of each year's

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3 As we have observed in the preceding note, the technology for growing corn relates the total observed production of corn to the observed quantity of

production to consume and how much to invest, it is gross output that is the relevant constraint. To be sure, it is investment net of depreciation that determines the change in the amount of corn-capital available for production in the following year. However, this should not deflect attention from the fact that Robinson first had to grow a gross investment in order get that net amount.

Thus, while these is a role for net output concepts in the overall framework of the national accounts, it is emphatically not to be found on the capacity side of these accounts. And, with this in his mind, Robinson's solution to the accounting problem follows more or less immediately. The accounts must be consistent with input and output definitions of the production function and any restrictions on the form of the technology must translate into restrictions on the way the data is organized. In the case that the production function exhibits constant returns to scale, for example, we know that gross output equals the sum of capital and labor, each multiplied by its respective marginal productivity. If, in addition, the inputs are paid the value of their marginal product (i.e., the wage w_t equals the marginal product of labor, etc.), the result is the familiar GNP identity:

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capital and labor used to produce that output: $Q_t = F(K_{t-1}, \bar{L}_t, t)$. Any attempt to write a production function in terms net output, i.e. $N_t = Q_t - \delta K_{t-1} = F^*(K_{t-1}, \bar{L}_t, t)$, would leave Robinson wondering about the δK_t bushels of corn he sees growing in his field: they're not included in the net production function $F^*(K_{t-1}, \bar{L}_t, t)$, so how did they get produced?

$$GNP_t = p_tQ_t = c_tK_{t-1} + w_tL_t. \qquad (2)$$

Since there is only one output in Robinson's economy, we can express all other values in terms of corn. The price of corn in terms of corn is therefore equal to one in every year, but we will continue to represent the output price with the explicit symbol p_t for the sake of clarity. Given this accounting convention, the implicit wage that Robinson earns as a return to his work effort is denominated in units of corn, and the gross return to capital is treated similarly.

The data shown in Table 1 is sufficient to built the production account. Columns (2) and (3) show the quantities of labor and capital, respectively, and column (4) gives the resulting amount of corn-output. The last two columns given the wage and gross return to capital, and multiplication of input prices and quantities confirms that the GNP identity (2) holds for the data of Table 1. Conversely, the accounts built on this data set constitute a sufficient set of information about the production possibilities of this simple corn economy, in the important sense that the data may be used to estimate the underlying technology. For example, Robinson the Econometrician could use these accounts to learn that the production function of his economy has the Cobb-Douglas form $Q_t = .5\times[K_{t-1}^{.25}(100\times L_t)^{.75}]$

C. The Wealth of Robinson's Nation

The production account allows Robinson to measure the parameters of the supply side of his economy, and to determine the capacity constraint at each point in time. But, it is clear from Figure 1 that this is only part of the story, and that some account has to be given of the factors which determine the optimal consumption path (the point $\mathcal{E}$ in that figure). Since this path is the result of utility maximization subject to the capacity constraints, the basic accounting problem is to assemble data in such a way that the parameters of the underlying utility function (equation 1) can be estimated.

This problem is, however, harder to solve than the supply side problem of building the production account. The production function involved a relation between variables that could be measured every year: the inputs of corn-capital and labor, and the resulting output of corn. By contrast, the utility function involves a relation between the amount of corn consumed in each future period of Robinson's life, and the total utility obtained from that stream of future consumption. Neither side of this equation is contemporaneously observable: the utility indicator is a subjective index which is never observed, and most of the future consumption path is seen only in the future.

Fortunately, the classic work of Irving Fisher (1930) comes to the rescue. In Figure 1, there is a tangent line $\mathcal{CD}$ through the point $\mathcal{E}$ separating the production possibility frontier $\mathcal{AB}$ from the indifference curve $\mathcal{II}$. This line defines the Fisherian wealth of Robinson's economy as the present value of the optimal consumption stream, discounted at the rate of interest implied by the slope of the wealth line (the term "$1+i$" in Figure 1):

$$W_0 = \sum_{t=0}^{\infty} \frac{C_t}{\Pi_0^t(1+i_s)} \qquad (3)$$

Finding the consumption path which maximizes wealth, given the correct interest rates, is equivalent to maximizing the original Ramsey utility function in (1).[4] Here, however, the left hand side of the equation is denominated in potentially observable units of corn: indeed, it is the amount of corn that Robinson would accept today in order to forego the future stream of consumption.

However, there is still the problem that this "cash-out" amount is not observable unless the buy-out is actually offered, and the right hand side is still a function of future consumption flows. Of course, if these future flows are constant over time, as in the steady-state example of Table 1, then the sum of future consumption can be computed: Column 2 of Table 2 shows the present value of 40 units of corn consumed in every future year (discounted at the constant rate of 2.5 percent, which is the gross return to capital in Table 1 less the 10 percent rate of depreciation).[5] Wealth, in this case, is seen to equal 1600 bushels of corn. But, this is a very special case, and in general the present value of wealth cannot be obtained directly from past and present data on consumption.

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4 We have used, here, the convention that Robinson maximizes wealth over an infinite horizon. However, there will inevitably be a time T after which consumption and labor input take on zero values.

5 The gross return to capital is equal to the value of capital's marginal product. This gross return must, however, cover both the opportunity cost of capital, i, and the cost of depreciation, δ. This is the Jorgensonian user cost $c = (i+\delta)p$. The discount rate i is used in the computation of wealth. In Table 1, the gross return is shown in Column (8) and net return in Column (9).

Further progress in analyzing this simple economy can, however, be made by observing that when the economy follows the utility maximizing path, wealth is also equal to the present value of Robinson's labor income plus the value of his initial endowment of corn:

$$W_0 = \sum_{t=0}^{\infty} \frac{C_t}{\Pi_0^t(1+i_s)} = \sum_{t=0}^{\infty} \frac{w_t L_t}{\Pi_0^t(1+i_s)} + p_0 K_0 \quad . \tag{4}$$

The equalities are the intertemporal counterpart of the GNP identity in (2): where the latter relates the value of gross national product to the value of the inputs of capital and labor used to produce GNP, the expression in (4) relates the value intertemporal national product (wealth) to the present value of the inputs used in generating wealth. Just as the GNP is the fundamental accounting identity of the annual capacity accounts, equation (4) is the fundamental equation of the welfare side of the accounts.

Because of its importance, several remarks about equation (4) are in order. First, this concept of total the wealth differs from the more usual notion of wealth as the value of society's capital (the p_0K_0 term in equation (4)). Only 100 units of the 1600 units of total wealth in Table 2 is due to capital, with the rest due to the future flow of labor service. The importance of the labor component of wealth finds empirical support in the recent work of Jorgenson and Fraumeni, but this view must be interpreted with some care. If, for example, Robinson were to purchase his labor input (from, say, the natives of an adjacent island), then the present value of labor in the intertemporal accounting identity (4) would net out against the flow of consumption as a cost, leaving the net value of future consumption flows just equal to value of capital. In this case, the wealth (and total net welfare) of Robinson's little nation can be monitored an an annual basis.[6]

The second general remark concerns the role of annual investments. Annual output is divided between consumption and gross investment, but the latter is nowhere apparent in the wealth identity. This reflects an important aspect of the optimal investment plan: every unit of output set aside for investment is one unit not available for consumption, and this defines the opportunity cost of the investment. If investment is done properly, this cost of consumption foregone is just balanced by the present value of the additional future consumption made available for the investment. In other words, optimal investment is just a shifting of current consumption to the future, and therefore does not increase total wealth. This fact was a key to deriving the intertemporal accounting identity (4).

D. The Role of Net Product

Were it possible to measure total national wealth in every year, as per the identity (4), then Robinson would have a complete picture of his economy.

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6 If, on the other hand, Robinson experienced disutility from working [i.e., if leisure were incorporated in his utility function (1)], then the total endowment of time available for both labor and leisure would replace the labor variable on the right hand side of (4).

But, as this is generally not possible, an alternative accounting strategy has been developed. In an important contribution to the subject, Weitzman (1976) demonstrated that there is another way to get at the wealth-welfare side of the economy: he showed that, once optimal consumption is determined for each year (i.e. the path of consumption which maximizes intertemporal utility in equation (1)), there is another path which also maximizes utility: consumption plus the net change in capital.[7] But, consumption plus the net change in capital is equivalent to our previous definition of net output,[8] implying that annual estimates of net output are a component of the wealth-welfare expression defined above. It then follows that net output is the appropriate indicator of the each year's contribution to economic welfare, just as gross output was the appropriate indicator of the capacity constraint prevailing in that year.

The actual situation is, however, somewhat more complicated. There are,

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7 Put more formally, if the path $\{C_t^*\}$ maximizes intertemporal utility function (1), then the path $\{C_t^*+\Delta K_t^*\}$ also maximizes utility. This is reflected in equation (4) by the fact that only the value of the initial endowment of capital affects wealth. Intuitively, any addition to the stock of capital which is made after the initial year is simply a decision to shift consumption to future years. If this is done optimally, the present value of consumption foregone by ΔK is just equal to the present value of the subsequent consumption stream, leaving total wealth unchanged.

8 Recall, here, that gross output is divided between consumption and investment, $Q_t=C_t+I_t$, that net output is defined as $N_t=Q_t-\delta K_t^*$, and that $\Delta K_t^*=I_t-\delta K_t$. Direct substitution yields the result that $N_t=C_t+\Delta K_t^*$. But, this is a special case, as we will see in the following section, and this equality does not hold in general.

in fact, three distinct concepts of net product that are viable candidates for the role of annual welfare indicator: first, there is the net output measure discussed above; second, there is net income, defined in the usual sense of the net income earned by the owners of capital (iK) plus the income received by workers (wL); and finally, there is the famous Haig-Simons definition of income as consumption plus change in net worth.[9] When depreciation has the geometric form, all three definitions turn out to be equivalent, but Haig-Simons and net income are a consequence of the fundamental wealth identity (4), and are equivalent whether or not depreciation is constant. However, these two concepts of income are equivalent to net product only when depreciation is geometric (more on this point later).

The three concepts of net product are shown in the final columns of Table 2. In view of footnote (7), it is hardly surprising that each has the value of 40 bushels of corn. Nor is it a coincidence that annual consumption also

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[9] The value of net output is defined, following our previous notation, as $p_tN_t = p_tQ_t - p_t\delta K_{t-1}$. Net income is defined, formally, as $Y_t = i_tK_{t-1} + w_tL_t$, while the Haig-Simons definition of income as consumption plus change in net worth implies $S_t = p_tC_t^* + p_t\Delta K_t^*$. Note that the GNP identity (2) relates GNP to the capital income gross of depreciation plus labor income: recalling the condition $c = (i+\delta)p$, the GNP identity can be expressed as $p_tQ_t = [i_t+\delta]p_tK_{t-1} + w_tL_t$, or collecting terms, as $p_tQ_t = i_tp_tK_{t-1} + w_tL_t + \delta K_{t-1} = Y_t + D_t$, where D_t is the total depreciation cost. Manipulation of the fundamental wealth identity (4) establishes the equivalence of net income and Haig-Simons income: $S_t = p_tC_t^* + p_t\Delta K_t^* = i_tp_tK_{t-1} + w_tL_t = Y_t$.

equals 40 bushels, since these tables portray a steady state solution to Robinson's economic problem, and investment is therefore just sufficient to replace the depreciated capital. A more interesting application of the net product concept arises if Robinson were to increase output by using up his capital at a more rapid rate.

To illustrate this, let us suppose that at the end of year 5, Robinson discovers that gross output can be increased by devoting more of his labor time to tending the corn (e.g. weeding) and less time to, say, replenishing the fertility of the soil. This alternative production plan leads to an immediate 10 percent increase in productivity, and gross output rises from 50 to 55 bushels of corn [Column (4) of Table 3]. But let us also suppose that the gain in gross output has been achieved at the expense of a more rapid rate of depreciation (from 10 percent to 20 percent) because less time is spent maintaining the soil. The higher rate of depreciation leads to an immediate drop in net product (as measured by any of the three concepts) from 40 bushels to 35. Thus, while gross output and consumption both rise in the short run in response to the change, and decline only in later years, the net measures of product fall immediately and signal the fact that these short run gains are made at the expense of long run consumption.

This establishes the value of net measures of national economic performance. But, it does not invalidate the gross measure, for its appropriate use. Robinson the Econometrician could still use the gross production accounts of Table 3 to learn that the new production function of his economy has the Cobb-Douglas form $Q_t = .55\times[K_{t-1}^{.25}(100\times L_t)^{.75}]$.

TABLE 3

(1) YEAR	(2) LABOR INPUT	(3) CAPITAL INPUT	(4) OUTPUT	(5) INVEST.	(6) CONS.	(7) WAGE	(8) GROSS RETURN	(9) NET RETURN
6	1	100	55	10	45	41	0.138	-0.063
7	1	90	54	10	44	40	0.149	-0.051
8	1	82	52	10	42	39	0.160	-0.040
9	1	76	51	10	41	38	0.170	-0.030
10	1	70	50	10	40	38	0.179	-0.021
11	1	66	50	10	40	37	0.187	-0.013
12	1	63	49	10	39	37	0.194	-0.006
13	1	60	49	10	39	36	0.200	0.000
14	1	58	48	10	38	36	0.206	0.006
15	1	57	48	10	38	36	0.210	0.010

TABLE 4

(1) YEAR	(2) WEALTH	(3) GROSS INCOME	(4) DEPREC-IATION	(5) NET INCOME	(6) HAIG-SIMONS	(7) NET PRODUCT
6	1600	55	20	35	35	35
7	1590	54	18	36	36	36
8	1582	52	16	36	36	36
9	1576	51	15	36	36	36
10	1570	50	14	36	36	36
11	1566	50	13	36	36	36
12	1563	49	13	36	36	36
13	1560	49	12	36	36	36
14	1558	48	12	36	36	36
15	1557	48	11	36	36	36

E. The Fallacy of Net Output

The three concepts of net product are shown as equivalent in Tables 2 and 4, but this equivalence is an artifact of the assumption that depreciation is constant. Only the Haig-Simons and net income measures are really equivalent, because they follow as a natural consequence of the two ways of defining national wealth in the identity (4). Net output, on the other hand, is the result of a persistent fallacy about the nature of depreciation, which is concealed when depreciation just happens to be constant.

The problem lies with the fact that there are two distinct aspects to the depreciation process: as capital ages, it tends to lose some of its productive capacity (it may require more maintenance, break down more often, or operate more slowly or with less accuracy). This process culminates with the retirement of the asset from service, at which point its productive capacity reaches zero. This loss of physical capacity is accompanied by a parallel loss in the value of the asset as it ages: a five year old truck is not as valuable as a new truck because it has fewer years left to earn income, and because it may also have higher operating costs. This loss in value as the truck ages is called "Hicksian depreciation," which is defined formally as the amount of money that must be set aside in order to keep the original capital value intact.

This concept of depreciation is illustrated in Table 5, for a piece of capital (say a truck) that lasts exactly five years, and does not lose any of its productive capacity until it is retired from service (this case is frequently called "one-hoss shay" depreciation). Because it retains its full productive capacity, the truck is able to earn exactly $100 in income (after operating expenses like maintenance) in each year of its life. With a discount rate of approximately 8 percent, the truck is worth the present value of $100 per year for five years, or $400 when brand new. In the following year, however, the truck has only four more years to earn income, so its value drops to $332 (the present value of $100 over the remaining four years). For the same reason, the value drops to $258 in the third year, then to $178, to $93, and finally to zero (this is shown in Column (3) of Table 5). Hicksian depreciation is the amount of money that must be put aside to keep the original $400 capital value intact, and (in the absence of inflation) this is just the change in the present values shown in Column (3).

This annual depreciation is recorded in Column (4). It is subtracted from the $100 gross income to yield net income (not net output!) in Column (5), and cumulated in Column (6) to form the depreciation reserve. When this reserve is added to the remaining value of the truck, it totals $400 in each year (Column (8)). Moreover, when the income generated by the depreciation reserve (Column (7)) is added to the net income of Column (5), the result is $32 in each year. This is just equal to the 8 percent return on the original $400 capital.

What does this example tell us about the fallacy of net output? Recall that net output is defined as gross output less the capital used up, or consumed, in production. In the Robinson Crusoe example, a fixed amount of capital was consumed in each year, and the cost of replacing this amount (i.e. the money needed to buy just enough corn to replace the quantity of corn-capital lost during the growing season). Is this cost of replacement the

TABLE 5

AGE IN YEARS	ANNUAL GROSS INCOME	ASSET PRESENT VALUE	ANNUAL DEPREC. IATION	ANNUAL NET INCOME	DEPREC. IATION RESERVE	RETURN ON DEPREC. RESERVE	TOTAL NET WORTH	RETURN ON NET WORTH
0-1	$100	$400	$68	$32	$0	$0	$400	$32
1-2	$100	$332	$74	$26	$68	$5	$400	$32
2-3	$100	$258	$80	$20	$142	$11	$400	$32
3-4	$100	$178	$86	$14	$222	$18	$400	$32
4-5	$100	$93	$93	$7	$307	$24	$400	$32

same as Hicksian depreciation? Herein lies the "rub". In an important paper, Jorgenson (1973) shows that Hicksian depreciation is the same as the value of capital consumed only when depreciation proceeds at a constant geometric rate. In all other cases, the two concepts differ.

The numbers in Table 5 illustrate the difference between depreciation and capital consumption. Column (4) shows that there is Hicksian depreciation in each of the first five years, and that it accelerates as the date of retirement approaches. On the other hand, capital consumption is zero in each of these fives years, because the truck is like a "one-hoss" shay and there is no capital consumed in producing output during these years. Since there is no capital consumed, and there are thus no replacement units to be purchased. In the "one-hoss" shay case, net and gross output are equal until the day that the asset is retired. Net income, on the other hand, falls in each year because of deprecation, and it thus the reflects the correct way to value the capital used up in production.

Net income, and its equivalent Haig-Simons counterpart, are the true measures of net product that should be included in the national accounts. These are the measures of net product that really make Weitzman's result "work," and the net output concept only works when depreciation happens to have the special geometric form. They are also the measures which serve as a bridge between the GNP account and the wealth account. While the GNP and wealth accounts portray different aspects of economic activity, they emanate from a common economic process, and the net income "bridge" serves as a reminder that the definitions and procedures used to construct one account must be consistent with those used in the other.

F. Accounting for Technological Change

We have thus far made no allowance for the possibility that Robinson might discover better ways to grow corn. Periodic breakthroughs in technical knowledge are, after all, one of the key sources of economic progress, and any accounting framework with a claim to validity should thus be able to handle this important phenomenon. Fortunately, this turns to be rather straight forward: if Robinson discovers a better way to grow corn, he will be able get more output from the same amount of capital and labor. A natural way to measure the amount of technical progress caused by an innovation is to measure the increase in output holding the amount of capital and labor constant. If output goes up by 10 percent when Robinson used 1 unit of labor and 100 units of capital (as per Table 1), we can to say that a 10 percent technical change has occurred, even if Robinson subsequently decided to change the amount of capital and labor used in producing corn.

This is, in formal terms, "Hicksian" technical change, which is defined as the shift in the aggregate production function holding capital and labor constant.[10] In a seminal paper, Solow (1957) demonstrated that this shift was equivalent to the residual growth in output not accounted for by the

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[10] In the notation of footnote 1, this shift is defined as the partial derivative of the production function $Q_t = F(K_{t-1}, L_t, t)$ with respect to t. This is the Hicksian way to measure technical change. The Harrodian way is to measure the shift in $F(\cdot)$ over time with respect to a constant marginal product of capital. The Harrodian rate is thus equal to the Hicksian rate divided by labor's share of income.

income-share weighted growth rates of capital and labor:

$$g_{R_t} = g_{Q_t} - \theta_{K_t} g_{K_t} - \theta_{L_t} g_{L_t} . \tag{5}$$

We have used, here the notational convention that a "g" represents the rate of growth of the variable in question (thus g_Q denotes the annual growth rate of output, and g_R the growth rate of the Solow residual). We have also used θ_K and θ_L to represent the income shares of capital and labor (in Table 1, these shares were .25 and .75, respectively).

All the variables on the left hand side of equation (5) can be measured from the kind of data presented in Table 1 (which, incidentally, shows zero technical change), so we can infer the shift in the production function as a residual. This procedure has been employed in a great many studies of economic growth [e.g., Solow (1957), Denison (1962), Jorgenson and Griliches (1967), the Bureau of Labor Statistics (1983), and Jorgenson, Gollop and Fraumeni (1987)]. However, this literature has been subject to an active debate over the correct measure of output to use in calculating the residual in equation (5): Solow (1957) and Denison (1962,1972) advocated the use of a net output measure in computing the residual, on the grounds that net output was a better measure of the consequence of technical change because it controlled for increases in gross output generated solely by a more rapid consumption of capital. Jorgenson and Griliches (1967,1972), on the other hand, argued for a gross output measure on the grounds that the issue pivoted on the shift in the production function, and not on the increase in welfare. This is the approach adopted in most of the recent literature on the measurement of production and growth.

Our discussion of capacity and welfare suggests that the gross output approach is, indeed, the right way to go about the problem of measuring changes in the capacity constraint due to technological innovation. This is an issue of the shift in the production function, which we have shown should be defined with respect to gross output. But this leaves the following question: if net output is <u>not</u> the correct way to incorporate welfare issues into the measurement of technical change, what is? The answer to this question comes from an unexpected direction: from the Harrod-Robinson-Rymes tradition of capital and technical change.

This alterative approach comes at the problem of capital and technology from the standpoint of capital as an input <u>produced</u> within the economic system. Because capital is produced (an intertemporal intermediate good, so to speak), improvements in technology mean that capital can be produced more cheaply, so that a given rate of saving will generated more capital. A shift in the production function will thus have a dual effect: it will increase the productivity of the existing factors, and result in more capital, other things equal. When both effects are counted as technical change, the result is the Harrodian concept of technical change (formally, the shift in the production function along a constant capital-output ratio). When technical change happens to be Harrod neutral at a rate of λ percent per year, the residual in (5) can be shown to equal labor's income share times the Harrodian rate.

The Harrodian framework is usually held out as a competing alternative to the Hicks-Solow framework, but Hulten (1979) has shown that both are, in fact, complementary approaches - <u>in exactly the same way that net and gross</u>

<u>output are complementary measures of capacity and welfare of economic growth</u>. In other words, the Harrodian framework is the right way to bring welfare concepts into the measurement of technical change, just as the Hicks-Solow approach is the right way to measures the capacity aspects of technical change. The demonstration of this result is somewhat technical, but it intuitively involves the following dichotomy: where the Hicks-Solow measures are derived from the production function and the GNP identity (2), the net welfare measure is derived from the wealth identity (4). Where the former produces the residual (5), the latter can be shown to produce another residual based on (4) which has the form:

$$g_D = \Sigma_t \, \omega_{C_t} g_{C_t} + \omega_{K_0} g_{K_0} - \Sigma_t \, \omega_{L_t} g_{L_t} - \omega_{K_T} g_{K_T} \qquad (6).$$

The growth rates are, again, denoted by the symbol g, but this new residual g_D equals the sum of the share-weighted growth rates of annual consumption plus initial capital, less the sum of the annual share-weighted growth rates of labor input, and the end-of-period amount of capital. The weights are the shares in total wealth, expressed as present values.[11]

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[11] The derivation of this residual is tedious, but is based on a variant of the wealth identity (4) in which the accounts stop in some future year T. Thus, equation (4) becomes:

To emphasize that the two residuals, (5) and (6), are complements and not competitors, it is possible to prove that the latter is the share-weighted sum of the latter:

$$g_D = \sum_{t=0}^{T} \omega_{Q_t} g_{R_t} = \sum_{t=0}^{T} \omega_{L_t} \lambda \rightarrow \lambda .$$

That is, the weight-sum of the annual Hicks-Solow residuals is equal to the weighted average of the annual Harrodian rates, and when the latter is constant, converges to the Harrodian rate.

It is important, in conclusion, to stress that the capacity-welfare nexus which is the subject of this essay finds an exact parallel in the Hicks and Harrod definitions of technical change. The former measures the shift in the capacity constraint which occurs when an innovation makes capital and labor more productive, and the latter measures the increment to wealth that can be achieved because capital is now easier to produce. Both measures should be included in any assessment of growth, just as both net income and gross output should be included in any sensible national accounts.

$$W_{0,T} = \sum_{t=0}^{T} \frac{p_t C_t}{\Pi_0^t (1+i_s)} + \frac{p_T K_T}{\Pi_0^T (1+i_s)} = \sum_{t=0}^{T} \frac{w_t L_t}{\Pi_0^t (1+i_s)} + p_0 K_0 .$$

The new residual can be derived from this expression and the weights are defined, accordingly, as

$$\omega_{C_t} = \frac{p_t C_t}{(W_{0,T}) \Pi_0^t (1+i_s)} , \quad \omega_{L_t} = \frac{w_t L_t}{(W_{0,T}) \Pi_0^t (1+i_s)} , \quad \omega_{K_T} = \frac{p_T K_T}{(W_{0,T}) \Pi_0^T (1+i_s)} , \quad \omega_{K_0} = \frac{p_0 K_0}{(W_{0,T})} .$$

II. Some Difficulties in Separating Capacity and Welfare Indicators of Economic Growth

We have outlined above the accounting framework appropriate for a simple model of intertemporal choice. The result was a tidy set of rules and procedures for representing both the capacity and welfare aspects of economic activity. The real world is, however, rarely neat and tidy, and the following remarks are offered as an illustration of some of the pitfalls that await the unwary national income accountant.

A. Endogenous Utility

In his parable, The Good Brahmin, Voltaire tells of a man whose great wisdom has brought fame and wealth, but not happiness. The Brahmin's misery arises from the realization that the more wisdom he acquires, the more he realizes how little he truly understands. His despair is deepened by a conversation with his neighbor, a poor peasant woman whose very ignorance is the source of great happiness and satisfaction with life. The parable ends with the paradox: "I concluded that although we may set great value upon happiness, we set a still greater upon reason. But after mature reflection upon this subject I still thought there was great madness in preferring reason to happiness."

This parable illustrates a basic problem with the growth analysis described in the preceding sections. Those sections accept the conventional neoclassical view that consumption is the essential basis of economic welfare. In the conventional framework, consumption is the only thing that contributes to utility [it is the only "argument" of Robinson's intertemporal utility function (1)], and the objective of society is generally assumed to be the maximization of utility (or, equally, of wealth, as in Figure 1). But this is an assumption about the real world, not an immutable fact. The story of the Good Brahmin is a reminder that not everyone equates happiness to consumption, and that materialism is not the only basis for well-being.

The logic of the preceding sections requires that we should attempt to measure both the change in an economy's productive capacity and the associated increments to economic welfare, in the form of the national income or wealth. But, this confronts the statistician with the following problem: if everything that increases or decreases utility really were a viable candidate for inclusion in the national accounts, the statistician would be asked to measure factors like the fear of crime, the love of beautiful sunsets, and the Good Brahmin's misery at contemplating the happiness of his ignorant neighbor. Such "quality-of-life" variables are so vague and so numerous, encompassing virtually every facet of human personality and experience, that a comprehensive accounting is virtually impossible. Some limit to the quality-of-life aspects of economic welfare is obviously needed.

One solution to this problem is to limit the national accounts to those commodities that are produced and consumed within the economic system (i.e., that are arguments of both the production function and the utility function). This strategy focuses on the full benefits and costs of production, and not just those benefits and costs that have a market valuation. It thus eliminates the need for valuing states of nature (and mind) which are not subject to economic choice, while encompassing important economic decisions, like the allocation of time between market and non-market activities (and labor versus leisure), and also allows for environmental spillovers. But, while this strategy succeeds in limiting the scope of the accounts, it is still too encompassing. Industrialization, for example, permits large gains in per capita income, but also brings increased urbanization, social alienation, and crime. If pollution and reduced leisure are counted as part of the price we pay for increased material well being, why not these other effects as well?

However, once we start down this path, we encounter an even deeper dilemma. Modern modes of behavior are necessary for the efficient operation of modern technology (e.g., literacy and logocentricity), and economic development and industrialization usually involve the adoption of different cultural patterns, often accompanied by an erosion of traditional religious and cultural values. The systemic changes in "world view" brought about by rapid economic growth are often opposed by traditional elements in society, and attempts to change the way individuals see the the world and make choices are undermined by cultural and institutional inertia. Economic development in many countries today is a struggle between traditional and modern value systems.

One implication of this conflict is that the choice of a future consumption path at any point in time also involves the choice of a utility function as well. This is very different for the canonical world of neoclassical growth theory, in which utility is taken as an exogenous "given" [viz. equation (1)] and can therefore be used as an independent index of the felicity associated with alternative growth paths. In the case of endogenous utility, this index of felicity is path dependent, meaning that the same amount of consumption at any point in time will yield a different amount of utility depending on the amount and composition of consumption in previous years. For example, the utility of a skiing vacation in the Alps may depend on whether or not one has ever skied before. Or, at the macroeconomic level, one society may have developed along traditional religious lines, despising wealth and materialism, while its neighbor has evolved along Western materialistic lines. Each may see their own path as being superior to the other, and if they do come to follow the same path after some point in time, they may assign a very different degree of felicity to exactly the same stream of future consumption.

A number of interesting measurement issues arise in the world of endogenous utility. How can one say that one path is unambiguously better than another when utility evolves endogenously along each different path? And, if this is true, what welfare meaning can be given to wealth and net income, which are defined with respect to the present value of the optimal consumption path? If we restrict attention to this optimal consumption path, then valuation can be based on that utility function which is unique to that path, despite its endogenous nature. However, while this may be sufficient for some valuation problems, the fact that the same path can have different utility assignments and wealth measures, which depend on past history, as in the example above, makes the valuation exercise somewhat problematic.

B. Endogenous Utility and Heterogeneous Income and Preferences

Basing a system of national accounts solely on the Robinson Crusoe parable of intertemporal choice described above has another flaw: Robinson was not alone on his island. He had a "man servant" Friday, and while the omission of Friday's interests from the parable is true to the 19th century origins of the story, this is hardly a recommendation for using this parable as a model for modern national accounting practice. But the introduction of additional agents into the model of intertemporal choice is not a simple task. With Friday in the picture, we have to consider just what it means to maximize total utility and wealth, as in Figure 1.

One possible solution to this problem is to assume that Robinson and Friday have the same tastes, and associate the utility function in Figure 1 with the common utility function. But there are two problems with this solution. First, there is no reason to believe that any two people in the world have the same preferences and, if anything, real world preferences are remarkably diverse. But, even, if preferences were identical, this not enough: they also have to have a very special form which guarantees that the resulting social indifference curve in Figure 1 is invariant to how income is distributed between Robinson and Friday.[12] In general, however, the social indifference curves depend on the distribution of income, and are thus

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[12] In formal terminology, they must be "homothetic," meaning that all "income expansion paths" must be parallel straight lines.

unstable. And, since the distribution of income is generally an endogenous feature of an economic system, the social indifference curves are endogenous to the system and we are back to the problem of the preceding section.

Even if, by some miracle of fate, the two protagonists happen to have the same homothetic utility function, there is a second problem to be considered when associating maximum income and wealth with maximum economic welfare. These conditions are enough to insure that the optimum point $\mathcal{E}$ in Figure 1 is economically efficient (Pareto Optimal), but consider the following problem. Suppose that Friday receives only subsistence wages, and that Robinson takes all the remaining consumption for himself. If all the increment to output is taken by Robinson, the growth of this economy looks very different to Friday than to his master. It makes little difference to Friday that growth in Pareto Optimal and that total wealth is maximized: he does not benefit and therefore assigns a very different value to the growth path than does Robinson. This implies that the welfare attached to a given amount of wealth depends on its distribution between Robinson and Friday.

The standard way to handle this problem is to aggregate individual preferences using a social welfare function. This approach implicitly assigns a weight to each person's utility, and the objective is to maximize this weighted total. This resulting social optimum is also a Pareto Optimum, and if we are willing to assume that the actual observed distribution of income, net of taxes and transfers, is the result of social welfare maximization, the national income statistician can proceed to collect income and wealth data with full confidence that the results can be interpreted as welfare indicators, as in the preceding sections.

However, anyone who is familiar with welfare economics knows that this solution is something of a pipe dream. The Arrow Impossibility Theorem reminds us that it is no easy task for society to agree on the appropriate social welfare function, and Robinson and Friday are almost certain to have different views about the correct social ethic. As they press their cases (in what ever political arena is available to them), the tides of politics are sure to produce some periods in which one view is ascendent, and other periods where the other view prevails. The result is a shifting social value assigned to the distribution of income and wealth, effectively endogenizing the indifference curves of Figure 1.

C. Aggregation Over Goods

These considerations suggest the link between utility and wealth is problematic, and that it is safer to limit the analysis of economic progress to the supply-side issue of capacity growth. However, it turns out that a complete separation of the utility and wealth aspects of growth (or supply and demand) runs afoul of many of the problems encountered in the attempt to aggregate heterogeneous utility functions. As with the utility case, aggregation over different industries and goods is possible only under very restrictive conditions (e.g., homotheticity), with the result that supply-side measures of capacity are not necessarily unique, but dependent on the growth path followed by the economy.[13]

The nature of this problem is illustrated by the following example. Suppose that Robinson Crusoe's economy consists of two goods, corn and wine, instead of just corn. We must now account for the production of both of these goods, and the standard way of dong this is through the production possibility frontier. The production possibility frontier ($\mathcal{AB}$ in Figure 2) represents all combinations of corn and wine that can be produced efficiently with a given amount of capital and labor, and a given level of technology. Robinson's utility function will determine which combination is selected, and if Robinson's preferences are more oriented to corn than wine, some point like *d*, will be chosen. The tangent line through this point defines the amount of GNP produced.

If the technology for producing one of the goods, say wine, improves, while the other technology remains unchanged, the combinations of corn and wine that can be produced with the original amount of capital and labor is now $\mathcal{AC}$. The growth accountant assigned to monitor this economy must now confront the question "How much has real GNP increased?" (which is equivalent to the Hicksian question "How much total technical change has occurred?", since

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[13] In formal terms, consistent aggregation over goods requires that the appropriate Divisia index should be a path dependent line integral. This occurs only under highly restrictive conditions, including the requirement that the underlying aggregation conditions are satisfied (Hulten (1973)). However, even when they are not, Divisia procedures can (and should) be used to indicate index values along the path actually followed. (Note that equations (5) and (6) are examples of the growth rate of a Divisia index, and that they must be integrated to obtain an index of the level of technical efficiency).

capital and labor have not changed). The answer to these questions obviously depends on the value that Robinson assigns to the two goods. If his preferences are more corn intensive, an improvement in the technical efficiency of corn production is more valuable to him than if he discovered a more efficient way to produce wine. (Put formally, the shift in the production possibility frontier from $\mathcal{AB}$ to $\mathcal{AC}$ is non-homothetic, so that a proportionate increase of output from d to e along the expansion path $O\mathcal{E}$ is less than the proportionate increase from f to g along the path $O\mathcal{F}$.)

This carries an important message for those searching for a purely supply-side analysis of aggregate economic growth: preferences matter. In general, the rate of growth of aggregate output (or total factor productivity) depends on preferences as well changes in technology, capital, and labor. Notions of "production function," "capacity," and "technical change" may be relevant at the disaggregated levels of production, i.e., the plant floor, but once input and output are aggregate to the level of industry or economy, supply-side purity is lost.

Preferences are even more deeply embedded in the problem of calculating the rate of technical change when innovations occur in the form of new goods (Diewert (1990)). The introduction of a new product (e.g., color television) expands Robinson's choice set, but because the good was previously unattainable, there is no way of estimating the value of the new good. In Figure 3, for example, $O\mathcal{A}$ units of good corn are produced in the first period and zero televisions are produced, because this good has not yet been introduced. In periods two and three, $O\mathcal{B}$ and $O\mathcal{C}$ units of corn are produced, but still no TVs. Finally, in period four, television is invented and

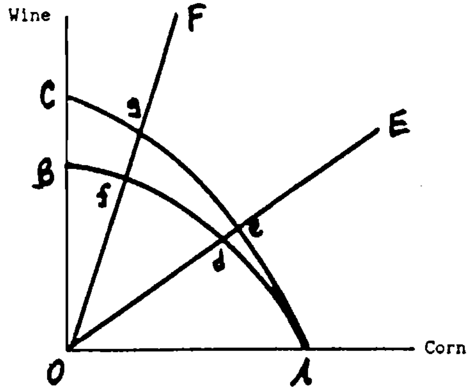

Figure 2

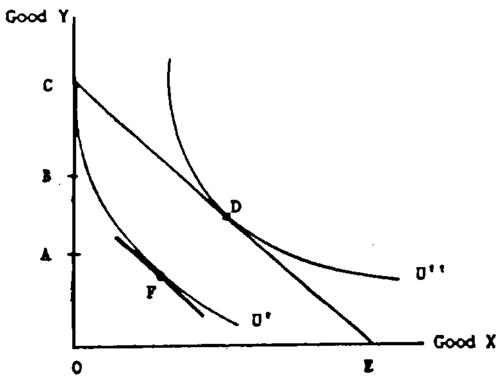

Figure 3

produced (at point $\mathcal{D}$) with the same factor intensity (hence the linear production possibility frontier) and marginal cost as corn. Because point D is on the same frontier as point $\mathcal{C}$, it is therefore deemed to be an equivalent amount of output from a purely supply-side perspective. But, Robinson is obviously better off after the new good appears (he's on a higher indifference curve U" after the introduction of the new good), and would be willing to pay an amount determined by $\mathcal{DF}$ in order not to give up TV (i.e. be forced back to the point $\mathcal{C}$ prevailing in the previous period).

An assessment of the productivity increase associated with the introduction of the new good, which is based only on the production side of the economy, misses the amount of technical change that has actually occurred. This problem is only made worse when the old good disappears entirely, as when the economy jumps from point $\mathcal{C}$ to point $\mathcal{E}$.

The new-goods problem is frequently involved when innovation gives rise to new products of higher "quality" - that is, goods which do what existing goods do, but do it better. The higher quality goods are, in effect, new goods which may or may not displace older, lower quality, rivals. But in either case, the message of Figure 3 is clear: a pure capacity approach to measuring the quantity of goods, where quality differentials are important, is likely to miss the true change in the quantity of the goods produced.

III. Concluding Comments

Sir John Hicks once observed that "The measurement of capital is one of the nastiest jobs that economists have set to statisticians (1981, page 204)".

Many readers of this essay will doubtless agree. Not only are there all the nasty problems of capital theory - the Cambridge Controversies, for example, and the issues raised in Section II of this paper - but there are also a host of practical issues that are even less tractable.[14] But, despite these difficulties, progress has been made, and it is important to avoid self inflicted wounds when designing a set of national income and wealth accounts.

The most serious of these wounds comes from the failure to link the national accounts to an underlying theoretical model. This linkage will not solve every problem - this is the message of Section II - but it will build an internal consistency into the accounts. It also helps clarify the roles of many of the important variables, as in the case of net and gross product. By deriving the accounting framework associated with the simple Robinson Crusoe model, we saw that gross and net product were not competing measures of national economic performance, but different aspects of the same process. In the same vein, the Hicks and Harrod measures of technical change were shown to be reveal different aspects of process of innovation. In sum, by pursuing this strategy, we were able to resolve the original question: "What is productivity: capacity of welfare measurement? It is both.

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[14] For a recent survey of the issues and problems associated with the theory and measurement of capital, see Hulten (1990).

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