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HOW SHOULD WE MEASURE SUSTAINABLE INCOME?

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Abstract

Growing concerns about long-run economic growth have led to calls for measures of "sustainable income." Traditional analyses rely on Hicksian income, which is consumption plus net investment. The present paper shows that Hicksian income corresponds to sustainable income only under implausibly limited circumstances. We define sustainable income and estimate its magnitude for the United States. The analysis and empirical estimates indicate, first, that consumption has historically been far below sustainable income; second, that conventional Hicksian measures of national income are poor proxies for sustainable income; and, third, that the true savings rate has declined significantly in the last two decades.

I. INTRODUCTION

With growing concern about our crowded globe and increased awareness of global environmental problems, environmentalists and governments have launched a crusade for "sustainable economic development." This concept, popularized by the report of the Brundtland Commission and often adopted by critics of economic growth, was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[2] The general notion here is that humanity is wasting its natural endowments -- "natural capital" such as appropriated natural resources

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[2] The World Commission on Environment and Development, *Our Common Future,* Oxford University Press, Oxford, 1987, p. 43.

like energy resources, nonfuel minerals, and soils; appropriated renewable resources like forests and aquifers; and vital environmental resources like clean air and water, the stock of genetic material, and the present climate. The dangers range from mundane ones of trash to the more ominous ones of economic decline or even climatic apocalypse.

A parallel effort among economists has been the effort to improve the traditional national-income accounts with measures that are both welfare-oriented rather than production oriented and extend the purview of the accounts beyond the traditional market sectors. This effort has been pursued by scholars for a quarter-century but in the last few years has been adopted by national governments. Two important milestones in this regard were the adoption of the U.N. System of National Accounts and the U.S. Commerce Department's Integrated Accounts.[3]

These two questions raise the fundamental question of exactly what we mean by "national income" or "social income." Economists use the term income in a wide variety of circumstances, but the concept of social income or national income is deep and elusive. As will be discussed below, there are two fundamental concepts of income -- one that is production based and a second, welfare-based concept that is close to the notion of sustainable income. They are, in general, quite distinct and give quite different numbers. This paper shows that the current attempts to improve national-income accounts to correct for their deficiencies as measures of sustainable income -- primarily by subtracting corrections for depletion of natural resources and degradation of the environment -- are quite defective and probably move in the wrong direction.

II. WHAT IS SOCIAL INCOME?

The origins of the concepts of "social income" or "national income" go back centuries, but we can distinguish two fundamental approaches -- one based on production and one based on wealth. The former is the basis of modern national-income accounting while the latter will be proposed as the appropriate concept for the measurement of sustainable income.

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[3]See Statistical Office of the United Nations, *SNA Handbook on Integrated Environmental and Economic Accounting: General Concepts*, New York, 1993 and U.S. Department of Commerce, *Survey of Current Business*, April 1994.

Production-based income (net national product)

The modern treatment of social income dates from the writings of J. R. Hicks, particularly in *Value and Capital.*[4] When economists and accountants measure national income and discuss sustainable income, they have almost universally relied upon the Hicksian definition. The discussion of social income in *Value and Capital* begins, "The purpose of income calculations in practical affairs is to give people an indication of the amount which they can consume without impoverishing themselves."[5] Hicks then goes on to define a measure, called "Income No. 1," to implement his definition of social income:

> *Income No. 1* is thus the maximum amount which can be spent during a period if there is to be an expectation of maintaining intact the capital value of prospective returns...; it equals Consumption plus Capital accumulation.[6]

This definition is what I will call "Hicksian income" -- the maximum amount that can be consumed while leaving capital intact. In practice, this means that income equals consumption plus a generalized measure of capital accumulation.

This concept is the standard definition of net national product used in the national-income accounts of virtually all nations today. It is *production-based* in the sense that it attempts to measure the rate of production at a given time. Such measures are not concerned with whether the economy is sustainable or not, whether production and consumption are growing or declining, and whether the economy is on a path toward prosperity or extinction.

From the narrow Hicksian definition it is but a small step to modern attempts to augment the national accounts. The purpose of these extensions is to expand the purview of the accounts to include a broader definition of "capital," particularly to include "natural capital" such as forests, mineral resources, and environmental resources. These measures correct net national product by subtracting estimates of resource depletion and environmental degradation. Other studies augment conventional national income by

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[4] J. R. Hicks, *Value and Capital,* Second Edition, Oxford: Clarendon Press, 1939.

[5] *Value and Capital*, p. 172.

[6] *Value and Capital*, p. 173, 178, emphasis added. This discussion ignores the subtlety of Hicks' discussion of price changes, interest rate effects, the difference between ex ante and ex post capital, and a number of other factors.

including corrections for human capital, government capital, the stock of research and development, etc.[7]

Wealth-based income (sustainable national income)

While standard measures of income are useful tools for measuring current production, they do not address the concerns about the sustainability of current decisions. I will propose a fundamentally different concept as the basis of measuring sustainable national income:

> *Definition.* Sustainable income is the maximum amount that a national can consume while ensuring that all future generations can have living standards that are at least as high as those of the current generation.

This definition is quite intuitive and simply measures the maximum sustainable level of consumption. It can also be thought of as a national real annuity or the maximum constant amount that a nation can spend out of its resource endowment.

The historical roots of the concept of sustainable income can be found in the writings at the turn of this century by Irving Fisher. He was the first to make the clear modern distinction between income and wealth, and his recounting of a trip from Lauterbrunnen to Zermatt describes his epiphany in the summer of 1894:

> It suddenly occurred to me while looking at a watering trough with its in-flow and out-flow, that the basic distinction needed to differentiated capital and income was substantially the same as the distinction between water in the trough and the flow into or out of it.[8]

Fisher's basic argument was that income is the yield on society's capital: "The income from any instrument is thus the flow of services rendered by that instrument. The income of a community is the total flow of services from all its instruments."[9] Although it forms the core of the notion of sustainable income that we will develop below, Fisher's approach was largely rejected by those who implemented national income accounts and personal income taxation.

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[7] See footnote 14.

[8] Irving Norton Fisher, *My Father, Irving Fisher*, Comet Press, New York, 1956, p. 123.

[9] Irving Fisher, *The Nature of Capital and Income*, Macmillan, New York, 1906, p. 101.

Conceptually, sustainable income can be thought of as the largest constant real consumption annuity that can generated by the generalized "wealth" represented by current and future technology and stocks of capital, labor, and resources. In other words, sustainable income is the maximum sustainable return on this generalized wealth. Because sustainable income is essentially the return on generalized wealth in the spirit of Irving Fisher, and ignoring a number of technical issues,[10] we call this definition the *Fisherian* or *consumption annuity* definition of income to distinguish it from the *Hicksian* or *capital intact* definition of income.

The notion used here is not new and is contained in much of the writing on sustainable income. Hicks actually used a similar concept in an alternative income concept that he called Income No. 3: "Income No. 3 must be defined as the maximum amount of money which the individual can spend this week, and still expect to be able to spend the same amount *in real terms* in each ensuing week."[11] In a similar vein, Robert Solow states, "I will assume that a sustainable path for the national economy is one that allows every future generation the option of being as well off as its predecessors."[12] Similarly, Robert Repetto states, "The core of the idea of sustainability, then, is the concept that current decisions should not impair the prospects for maintaining or improving future living standards."[13]

The pursuit of sustainability has been adopted by ecological and environmental economists, who have universally chosen Hicksian rather than Fisherian income.[14] A

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[10] Among the problems that still remain in this definition are index-number problems relating to the valuation of different consumption goods, the treatment of consumer durables, and the treatment of uncertainty.

[11] Hicks, *op. cit., Value and Capital*, p. 175.

[12] Robert Solow, "An Almost Practical Step Toward Sustainability," Resources for the Future Invited Lecture, Washington, D.C., October 8. 1992.

[13] *World Enough and Time*, Yale University Press, New Haven, Ct., 1986.

[14] See for example David Pearce, Edward Barbier, and Anil Markandya, *Sustainable Development: Economics and Environment in the Third World,* Edgar Elgar, Worcester, U. K., 1990; Herman E. Daly and John B. Cobb, Jr., *For the Common Good*, Boston, Beacon Press, 1989; R. Repetto, M. Wells, C. Beer, and F. Rossini, *Natural Resource Accounting for Indonesia*, Washington, D. C., World Resource Institute, 1987; David Pearce et al., *Blueprint for a Green Economy,* London, Earthscan, 1989.

careful statement is made by Daly and Cobb in their theoretical justification of their measure of sustainable income:

> Two adjustments to NNP are necessary to arrive at a good approximation to Hicksian income... One adjustment is a straightforward extension of the principle of depreciation to cover consumption of natural capital stocks depleted as a consequence of production. The other is to subtract defensive (regrettably necessary) expenditures made to defend ourselves from the unwanted side effects of growing aggregate production and consumption.[15]

British economists Pearce, Barbier, and Markandya take a slightly different tack by emphasizing the importance of "natural capital":

> We now consider a key necessary condition for achieving sustainable development....We summarize the key necessary condition as 'constancy of the natural capital stock.' More strictly, the requirement is for non-negative change in the stock of natural resources and environmental quality.[16]

Recently, the United Nations has adopted the Hicksian approach to measuring national income in its revised System of National Accounts (SNA). Although the SNA does not explicitly identify the proposed revisions in terms of a measure of sustainable income,[17] the underlying rationale in background papers described Hicksian Income as the desired target.[18]

III. ANALYSIS OF SUSTAINABLE INCOME

What is the relationship between conventionally measured national income (Hicksian income) and the new sustainable income (or Fisherian income)? In this section, we explore the two concepts and show that in general they are not equivalent.

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[15] *Op. cit.*, p. 71.

[16] *Op. cit.*, p. 4.

[17] See Statistical Office of the United Nations, *SNA Handbook on Integrated Environmental and Economic Accounting: General Concepts*, New York, 1993.

[18] See particularly Yusuf J. Ahmad, Salah El Serafy, and Ernst Lutz, *Environmental Accounting for Sustainable Development*, A UNEP-World Bank Symposium, The World Bank, Washington, D.C., 1989, especially Chapters 1, 2, and 3.

The analysis can be pursued using an approach developed by Martin Weitzman.[19] In a landmark paper in 1976, Weitzman investigated the question of how to measure "the stationary equivalent of future consumption," or what we call Fisherian income. He showed that in a situation where the only dynamic element is capital formation and where relative prices measure relative marginal productivities, then conventional net national product is equivalent to the stationary equivalent of future consumption. In other words, under these narrow conditions, *Fisherian income equals Hicksian income* (In Weitzman, Hicksian income is defined to be equal to consumption plus net change in capital stocks valued at appropriate efficiency prices).

To extend Weitzman's analysis -- to make a linkage between the measurable concept of Hicksian income and the desirable concept of sustainable or Fisherian income -- we need to consider additional dynamic elements other than produced capital goods selling at their efficiency prices. These additional elements will include non-produced but appropriated dynamic elements such as oil and forests, and unappropriated elements such as environmental resources and knowledge. In what follows, I will show how Weitzman's analysis applies when these additional elements are added.

For simplicity, I consider an economy with unchanging labor inputs, L(t), one conventional *produced* capital good, K(t), and a third *non-produced* factor, A(t), which shifts the production function over time. Capital includes the entire variety of conventional capital assets, including plant, equipment, and inventories. This analysis could easily be extended to include multiple consumption goods, homogeneous capital, and varieties of technological change, but these will not affect the basic point.

I will call the third factor, A(t), "knowledge capital," but it can be more broadly interpreted as knowledge capital, exogenous technological change, an environmental asset (such as the climate), or a residual factor. *The key point is that knowledge capital is not bought and sold in markets, is not accounted for in conventional national accounts, cannot be easily measured, and does not earn a normal rate of return on investment.*

For simplicity, assume that the consumption discount rate is a constant, r. Once we know the entire path of consumption, {C(s)}, we can easily calculate Fisherian or sustainable income, denoted by $\mathcal{C}(t)$. each period as:

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[19] Martin L. Weitzman, "On the Welfare Significance of National Product in a Dynamic Economy," *Quarterly Journal of Economics,* vol. 90, February 1976, pp. 156-162.

$$(1) \quad \int_t^\infty \mathcal{C}(t)\exp[-r(s-t)]ds = \int_t^\infty C(s)\exp[-r(s-t)]ds$$

or equivalently

$$(1') \quad \mathcal{C}(t) = r\left[\int_t^\infty C(s)\exp[-r(s-t)]ds\right]$$

Equation (1') shows that the measure of sustainable income is inherently a wealth-like measure as was emphasized by Irving Fisher and Paul Samuelson.[20] Indeed, it makes rigorous Irving Fisher's notion that income is the return to generalized social capital.[21]

We represent the production possibilities in terms of a standard neoclassical production function:

$$(2) \quad Y(t) = F[K(t), L(t), A(t)]$$

To facilitate analysis, we take F( ) to be constant returns to scale in measured inputs, K and L. A(t) is *unproduced* or unconventional capital items -- such as knowledge, environmental capital, oil reserves, etc. -- which we call knowledge capital to emphasize the importance of these intangible inputs. The aggregate production function is increasing returns in all factors, as is stressed in the "new growth theory." Under this assumption, plus the further one that measured inputs K and L are competitively priced, we can interpret the returns to measured factors as the efficiency or shadow prices associated with those factors. (These assumptions are for convenience. They are the implicit conventions taken in national income accounting and growth accounting, but we could in

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[20] Irving Fisher's view was cited above. Paul Samuelson's approach is contained in "The Evaluation of 'Social Income,'" in F. A. Lutz and D. C. Haig, eds., *The Theory of Capital,* London, Macmillan, 1961.

[21] This is quite different from Fisher's largely discredited view that income equals consumption. Henry Simons is reported to have quipped, "Let Fisher call whatever he likes income; but why should we tax what Fisher chooses to call income?" (quoted in Paul Samuelson, "Irving Fisher and the Theory of Capital," in William Fellner, ed., *Ten Studies in the Tradition of Irving Fisher*, John Wiley, New York, 1967, p. 26). If by consumption we mean the flow of current services *enjoyed by consumers*, this obviously can differ significantly from Fisherian income in (1') because some of Fisherian income may be set aside for the future.

principle use the true efficiency prices rather than the market prices if the former differed from the latter and could be estimated.)

Finally, we assume that production is divided between consumption and net investment, $K'(t) = \partial K(t)/\partial t$:

(3) $Y(t) = C(t) + K'(t)$

We would now like to determine if there is a definition of national income under which national income exactly equals sustainable income. For simplicity, we assume labor is constant so that C(t) is equal to per capita consumption. Using standard principles of dynamic optimization, we define the Hamiltonian of the optimization, $H(t)$, as:[22]

(4) $H(t) = C(t) + \lambda(t)K'(t) = C(t) + \lambda(t)\{F[K(t), L(t), A(t)] - C(t)\}$
$= H[C(t), K(t), \lambda(t), A(t)]$

where λ is the shadow price on produced capital in terms of consumption as the numeraire. When K is appropriately priced, $H(t)$ = net national product = Hicksian income. The necessary conditions for a program of accumulation to be optimal are that:

(5a) $\partial H(t)/\partial C(t) = 1 - \lambda(t) = 0$.

(5b) $\lambda'(t) = r\lambda(t) - \lambda(t)\,\partial F/\partial K(t)$

Taking the total time derivative of the Hamiltonian in (4) yields:

(6) $H'(t) = \partial H(t)/\partial C(t)C'(t) + \partial H(t)/\partial K(t)K'(t) + \partial H(t)/\partial\lambda(t)\lambda'(t) + \partial H(t)/\partial A(t)A'(t)$

The first term of the right hand side of (6) is zero from (5a). From (4) and (5b), the second two terms are $\partial H(t)/\partial K(t)K'(t) + \partial H(t)/\partial\lambda(t)\lambda'(t) = \lambda(t)\,\partial F/\partial K(t)\,K'(t) + K'(t)[r\lambda(t) - \lambda(t)\,\partial F/\partial K(t)] = K'(t)\,r\lambda(t)$. Further, from (4), $\partial H(t)/\partial A(t) = \partial F/\partial A(t)$.

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[22] This is an adaptation of the proof in Weitzman *op. cit.* that emphasizes the distinction between produced and non-produced increases in capital. A derivation along these lines is given in Karl Gustaf Lofgren, "Accounting for the Wealth of Nations: The Net versus Gross Output Controversy and Its Ramifications: Comment," *Swedish Journal of Economics*, vol. 94, Supplement 1992, pp. S25-S28.

Finally, because $\lambda(t) = 1$ when C(t) is the numeraire, the change in NNP or Hicksian income is given by:

$$(7) \quad H'(t) = r\,K'(t) + \partial F/\partial A(t)\,A'(t) = r\{H(t) - C(t)\} + \partial F/\partial A(t)\,A'(t)$$

Equation (7) is a Bernoulli equation whose solution is given by:

$$\mathcal{C}(t) = H(t) + \int_t^\infty \partial F/\partial A(t)\,A'(t)\exp[-(s-t)]ds = r\int_t^\infty C(s)\exp[-r(s-t)]ds$$

or

$$(8) \quad \mathcal{C}(t) = C(t) + K'(t) + \int_t^\infty \partial F/\partial A(t)\,A'(t)\exp[-(s-t)]ds$$

Equation (8) shows that the Fisherian income [$\mathcal{C}(t)$] equals narrow Hicksian income (the Hamiltonian, H) plus a term which reflects the increment to future output that results from the accumulation of knowledge and other intangible capital stocks. From this, two important propositions immediately follow:

Proposition 1 (from Weitzman). When there is no technological change or other form of non-produced capital, net national product measures sustainable income. In other words, sustainable income equals net national product plus a correction for the growth of knowledge capital or technological change. Where A(t) is constant, reflecting no growth in knowledge capital, the last term in equation (8) is zero, so sustainable income reduces to NNP.

Proposition 1 also shows why current thinking on the measurement of sustainable income is incomplete and can be misleading. If we think of K'(t) as the net accumulation of capital (at efficiency prices), then it is appropriate to include all forms of capital, including subsoil assets, forest assets, environmental assets, etc. But in doing so, two important factors are often omitted: First, the discoveries of new assets must be included. Hence, when a country discovers new reserves of petroleum, these should be included just as depletion of the stock of existing natural assets should be debited. Second, and far more important quantitatively, most studies of augmented income omit intangible capital in the form of technology and "knowledge capital."[23] These are clearly very difficult to

[23] This result was clearly indicated in Weitzman, *op. cit.*, but was not highlighted.

measure, but the invention of optical fibers is just as much an increment to our potential consumption as is discovery of a new vein of copper.

Proposition 2. The appropriate definition of sustainable income must include a term to reflect the contribution of future technological changes, as shown in equation (8). That is, the appropriate definition of sustainable income is *not* net national product in the usual sense of consumption plus conventional capital formation. It must include the entire contribution of non-produced capital, including intangible sources such as technological change. The reason is straightforward: Sustainable income must include all changing stocks.[24] Hence to the extent that useful knowledge is accumulated, NNP as conventionally measured will understate true sustainable income because it excludes the growth in knowledge capital.

It is curious that current approaches to measuring sustainable income implicitly assume technological stagnation and omit the second term in (8).[25] Clearly, the case of technological stagnation is not the general case. The important result is that when there is a non-marketable knowledge capital not captured in the capital accumulation accounts, then sustainable income will differ conceptually from even the most carefully constructed measure of net national product of Hicksian income.

The alternative measures of income are shown in Table 1.

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[24] The case of intangible and perhaps unmeasurable knowledge stocks is analytically equivalent to exogenous and non-profit-oriented technological change.

[25] See the references in footnote 14. All these studies omit knowledge capital.

Table 1. **Alternative Concepts of Income**

Net national product (or net domestic product). The conventional measure of national income. Equals consumption expenditures plus net investment during a year in structures, equipment, and inventories produced by (or in) a nation along with net foreign investment.

Hicksian income (or narrow Hicksian income). Net national product augmented by net investment in non-marketed capital such as subsoil assets (e.g., oil), renewable assets (e.g., forests), and environmental assets (e.g., carbon dioxide emissions).

Sustainable income (or Fisherian income). Maximum indefinitely sustainable level of consumption. Alternatively, equal to the rate of return on the present value of all future consumption.

Augmented Hicksian income. Consumption plus the value of the increase in all forms of capital and other dynamic elements, including capital, land, human capital, knowledge and technological capital, etc. Equals Fisherian income when capital is valued at its efficiency prices.

Four examples

The analysis of sustainable income is inherently complicated, so I will present four examples to illustrate the approach and compare it will other approaches.

Example 1: the Fisher diagram. We can show the difference between sustainable income and other concepts using a generalized Fisher diagram in Figure 1. The top half shows the consumption possibilities between future and present consumption assuming for simplicity that labor is constant; the bottom half shows how current production is divided between current consumption and current investment. The diagram shows the

relationship between conventionally calculated NNP and sustainable income *(SI)* as defined here. In the absence of technological change, *SI* equals NNP and the two definitions of income are identical. With technological change, however, the highest sustainable consumption at *SI* exceeds current *NNP*.

Example 2: Example with knowledge capital. The next example shows how conventionally measured NNP or Hicksian income will understate sustainable consumption in a model with explicit knowledge capital. For this example, I assume that knowledge capital is a perfect substitute for physical capital.[26] Assume that production is by a Cobb-Douglas production function of the form $Y(t) =[K(t)+A(t)]^{\alpha} [L(t)]^{1-\alpha}$. Consider a path in which labor grows at rate n while output and capital grow at rate g.

Under the narrow Hicksian definition of income, national income equals consumption plus net capital accumulation:

$$(9) \qquad NNP(t) = C(t) + K'(t)$$

which is the standard definition of net national product. Sustainable income is the level of total consumption that would keep per capita consumption constant. Under this definition, Fisherian income [$\mathcal{C}(t)$] is:

$$(10) \qquad \mathcal{C}(t) = (r-n)C(t)/(r-g).$$

We show that $\mathcal{C}(t)$ equals NNP only when there is no technological change [i. e., when A(t) is constant]. Define the difference between Fisherian income and NNP as ϕ:

$$(11) \qquad \phi(t) = \mathcal{C}(t) - NNP(t) = (r-n)C(t)/(r-g) - C(t) - K'(t).$$

Hence:

$$(12) \qquad (r-g)\,\phi(t) = (r-n)C(t) - (r-g)[\,C(t) + K'(t)] = -rK'(t) + gC(t) + gK'(t) - nC(t)$$

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[26] A number of readers of a previous draft have commented that this assumption begs the fundamental question because there is a possibility that natural capital is essential and knowledge cannot substitute for natural capital. Whatever the validity of the factual contention about the substitutability of natural capital and knowledge, the analytical point is easily handled by making the production function more general, say Y(t) = F[K(t), A(t), L(t)]. The argument will go through for this case but the algebra is tedious.

Differentiating the national output equation in (9) gives $Y'(t) = C'(t) + K''(t) = gC(t) + gK'(t)$ while differentiating the production function gives $Y'(t) = rK'(t) + rA'(t) + wL'(t)$, where w is the marginal product of labor. Combining these yields $gC(t) + gK'(t) = rK'(t) + rA'(t) + wL'(t)$, which with (12) gives:

(13) $(r-g)\,\phi(t) = -rK'(t) + gC(t) + gK'(t) - nC(t) = rA'(t) + wL'(t) - nC(t)$

Along a path where per capita consumption is maximized, we know that all wages are consumed, implying that $C(t) = wL(t) = wL'(t)/n$, so the right hand side of (13) reduces to $rA'(t)$. By comparing (12) and (13) we see that $\phi(t)$ is zero only when $A'(t) = 0$, showing that NNP and Fisherian income are identical only in the case where there is no technological change. It is also easily seen as well that Fisherian income exceeds NNP when technological change is positive.

Example 3: a numerical example. Consider a standard model of balanced growth. Assume a constant returns to scale, Cobb-Douglas production function with capital elasticity of 0.25. It is assumed that the net savings rate is 0.15, the depreciation rate on capital is 0.10 per year, and that labor is constant and equal to 1. We take alternative values of the rate of labor-augmenting technological change as $h = 0$ (the stationary economy) and $h = 0.03$ (the progressive economy much like that of the last century in the West). Table 2 shows how we would measure the different concepts using these assumptions. This shows how sustainable income will exceed NNP when technology is improving. Note in addition that the true savings rate is far above the conventionally measured savings rate.

Table 2. **Values of Economic Variables and Different Definitions of Income in Balanced Growth Paths**

Initial values*	***Stationary state*** ***(h = 0)***	***Progressive state*** ***(h = .03)***
Gross Output (GNP)	1.145	1.049
Capital	1.717	1.210
Consumption	0.973	0.892
Real interest rate	0.067	0.117
Hicksian income (NNP)	0.973	0.928
Fisherian income (SI)	0.973	1.200
Measured savings rate**	0.000	0.039
True savings rate***	0.000	0.256

*Initial values are those for period 0; subsequent values are initial values multiplier by e^{ht}.

** The difference between NNP and consumption divided by NNP.

*** The difference between sustainable and actual consumption divided by sustainable consumption.

Example 4: the wayward spaceship. For gloomy souls, how would our measures cope with a situation where we are simply eating our endowment? A polar case, which might appeal to ecological economists, is the "wayward-spaceship economy." In this situation, we have found ourselves on board a large spaceship adrift in the universe. The spaceship has a fixed endowment of food, a given number of people who either live forever or have replacement children, no way of producing new food, and no technology for making the food stretch further.

What is sustainable income in this economy? Clearly zero for both the Hicksian and Fisherian approaches. Under the Hicksian approach, any consumption must simply draw down the stock of food, so the sum of consumption and change in food capital is zero. Under the Fisherian approach, the maximum sustainable consumption rate is the endowment divided by infinity, which is zero. This example is perhaps the mental vision

that ecological economists have in mind when they construct national-output accounts using the Hicksian construct. In this case, they would be correct to subtract the depletion of essential natural resources from consumption in the wayward-spaceship economy: the Hicksian and the Fisherian definitions coincide because there is no technological advance.

However, conventional NNP can go astray when there is technological advance. Suppose that scientists perfect a process whereby in T years solar energy can recycle all waste into food. Using this technology, the spaceship can produce all the food that the voyagers need. In this case, sustainable income is clearly R_0/T, where R_0 is the initial endowment of food and T is the years until the technological breakthrough. By contrast, NNP is calculated to be zero for the first T years. This example shows how the omission of technological change can lead to a significant bias in estimating sustainable income.

IV. MEASURING SUSTAINABLE INCOME

Analytical background

In this section I derive two estimates of sustainable income and compare them with conventional measures of net national product. The two new measures are the Fisherian measure, $\mathcal{C}(t)$, and the augmented Hicksian measure, $\mathcal{I}(t)$. The Fisherian or consumption annuity measure has been discussed above and is in principle straightforward to measure: it takes the present value of future consumption and pays out the perpetual annuity defined in equation (1'). For Fisherian income, the only major issue is projecting the stream of future consumption.

The second measure follows the logic of current approaches to measuring sustainable income by estimating sustainable income as current consumption plus generalized capital formation, including technological change. This alternative measure, which I call *augmented Hicksian income*, uses equation (8); it corrects for the defects in narrow Hicksian income by including a correction for the growth in knowledge capital.

The approach here, sketched above for example 2, takes the oversimplified but tractable approach of redefining knowledge capital so that it is a perfect substitute for produced capital. This assumption is primarily for expository purposes and is in the nature of a change of units rather than a substantive economic assumption. Under this assumption, we redefine knowledge capital so that the new production function is

$$(2') \qquad Y(t) = G[\theta\{K(t) + A(t)\}, L(t)]$$

In equation (2'), $\theta\{K(t) + A(t)\}$ represents the services of capital and knowledge. I take the yield rate θ as constant over time for simplicity and normalize it at $\theta = 1$. We can then rewrite equation (8) as:

$$(8') \quad \mathcal{C}(t) = H(t) + \int_t^{\infty} \partial F/\partial A(t)\, A'(t)\exp[-(s-t)]ds = C(t) + K'(t) + A'(t)$$

In other words, to obtain a measure of sustainable income, we need to augment NNP with a measure of the value of the increase in the stock of knowledge capital.

But where in the world are we to find a measure of the increase in the stock of knowledge capital? In fact, we can obtain this measure from an estimate of TFP, total factor productivity. From (2'), since the increase in output is equal to $Y'(t) = G_1[K'(t) + A'(t)] + G_2L'(t)$, it follows that $A'(t) = \{Y'(t) - G_1K'(t) - G_2L'(t)\}/G_1$. Under the competitive assumptions, $G_1 = r$, so the measure of $A'(t)$ is the non-produced part of output growth (what Dale Jorgenson calls the "exogenous growth component"[27]) divided by the rate of return on capital. Hence $A'(t) = [A'(t) - rK'(t) - wL'(t)]/r$, which is the increase in output not accounted for by the increase in inputs divided by the real discount rate.

Empirical application

The actual estimation of both of the measures of sustainable income is straightforward. I use national data for the U.S. from a variety of sources (see the Appendix for a description). The period examined is from 1800 to 1993, using per capita data. Clearly, the quality of the data is much more questionable the further we go before World War II. Sustainable national income is defined as per capita sustainable income times population.

Figures 2 and 3 show estimates of conventionally measured NNP, Fisherian income ($\mathcal{C}$), and augmented Hicksian income ($\mathcal{H}$). The first figure shows the estimates for the entire period 1800-1993, while the second shows estimates for the period since World War II. In each case, different measures of income are compared with actual consumption expenditures. Figures 4 and 5 show the "true national savings rate," measured as the difference between sustainable income and consumption divided by sustainable income and comparing that with conventionally measured net national savings rates.

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[27] Dale W. Jorgenson, "Investment and Economic Growth," *The Simon Kuznets Lectures*, Yale University, November 11-13, 1994.

The major surprise from this new approach is to see that for most of the last 200 years, the true savings rate has been between 30 and 40 percent of sustainable income. The rate is clearly much higher than the conventional savings rate from NNP, which has averaged around 10 percent of NNP since 1870. The high sustainable savings rate reflects the fact that each generation has consumed only a fraction of what it could have consumed if it were to consume the social dividend on current capital and future technological change. Different savings rates are shown in Table 3.

All measures show a marked drop in the true savings rate since the early 1970s. The Fisherian measure and the augmented Hicksian measure give estimates of true saving today between 15 and 20 percent of sustainable income, whereas the conventional measure is around 3 percent of NNP. The drop in the savings rate on NNP is due to the decline in net investment in domestic capital and in net foreign investment. The drop in the savings rate on sustainable income includes the drop in NNP investment plus the decline in "knowledge investment," so the difference between the NNP and the sustainable-income savings rates shows the dramatic impact of the productivity-growth slowdown on savings.

V. DISCUSSION

This formal discussion of sustainable growth has skated over many of the deep and controversial issues. In this section, we review some of underlying issues and comment on other approaches.

Conventional national income accounting

What is the relationship between measurement of sustainable income and conventional national income accounting? There are numerous difference, but the major one is that national output is designed to be a measure of the current production of the nation rather than to be a measure of economic welfare. This point is clearly illustrated in the upper and lower parts of Figure 1. In this sense, net national product is closer to a measure of "consumable income" rather than to "sustainable income," for it measures the amount that could be *currently* consumed while leaving capital intact.

Within this conceptual definition of the national product, there are fundamental decisions about boundaries between those things that are included and those that are excluded from national output. Generally, the national accounts include all those items which are legal and are exchanged in the marketplace. This decision explains why leisure, most environmental services, illegal drugs, and home-cooked meals are not in the

conventional output measures (although they are increasingly being considered in satellite accounts).[28] All of the boundary disputes arise for sustainable income as well, but sustainable income and augmented accounts, such as the Nordhaus-Tobin Measure of Economic Welfare, attempt to push the boundaries to include all economic activity.[29]

Is one set of measures better than the other? Surely both are useful for different purposes. Conventional national accounts are critical for managing the business cycle, measuring the contribution of different sectors, and innumerable other items. But sustainable income is a missing link that tells us something fundamental that is missing from the national income accounts -- whether we are living beyond our means.

What is Consumption?

The issue of sustainable growth revolves around intertemporal choice. At the most fundamental level, it involves the question of whether this generation is consuming at an ethically indefensible rate. To ask this question raises the issue of what we mean by consumption.

As in the definition of the national accounts, most issues involve boundary disputes. Here it seems essential to use a broad definition of consumption and to include more than marketed consumption. Consumption should include not only conventional items such as food, clothing, and shelter, but also services and intangibles such as home production, recreation, leisure, and enjoying the environment. Economists take a bum rap every day because they focus on those parts of daily life that lie within the confines of the marketplace. But they do so the way dentists focus on teeth: not because market transactions are all there is to life but because that's what economists know most about. But all thoughtful economists and national-income accountants have been aware of this limitation and recognize that many of the best things in life are unpriced.[30]

Another boundary dispute arises because the economic approach is fundamentally anthropocentric. It counts the utility of people but not of dogs, birds, trees, or spores.

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[28] See U.S. Department of Commerce, *Survey of Current Business*, April 1994.

[29] See William D. Nordhaus and James Tobin, "Is Growth Obsolete?" in *Economic Growth,* National Bureau of Economic Research, New York, 1972; also in *Income and Wealth*, Volume 38, National Bureau of Economic Research, New York, 1973.

[30] The father of the U.S. national accounts, Simon Kuznets, was well aware of both. See his *National Income: A Summary of Findings*, Arno Press, New York, 1975, pp. 121ff.

When Bentham chose to maximize the greatest happiness of the greatest numbers, he was referring to the happiness of humans. An animal-rights advocate would include the utility of other feeling beings, and a marine ecologist might include the soul of the coral reef. Economists would of course respect these preferences and include the dogs' feelings in the utility of the animal-rights advocate and the soul of the coral reef in the preference of the marine ecologist. But economists traditionally do not include some abstractly defined preferences (e.g., feline felicity) or the intake of non-humans (e. g., cat food) in the consumption bundles that are to be optimized.[31]

The Capital-Intact Approach

In analyzing various concepts of sustainable growth in a modern context, ecological and environmental economists have emphasized the narrow Hicksian over the Fisherian approach. As noted above, the U. N. System of National Accounts has also adopted this approach. A few comments will indicate that, while interesting as a supplement to other measures, the narrow Hicksian approach is defective as a measure of economic welfare because it omits knowledge capital.

As the discussion above shows, the ecological interpretation of capital in the "capital intact" definition has generally been too restrictive in including only tangible capital assets. One way of seeing this is to note that an individual's wealth should contain not only the current value of financial and real assets but also the present value of labor income as well. By excluding human capital, 75 percent of national income is excluded.[32] Equally important is that in a technologically progressive society the value of income will be understated because the accumulation of knowledge capital is omitted. Hence, the ecological implementation of Hicksian income has a downward bias because of the exclusion of human and knowledge capital.

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[31] Bob Solow pointed out that this last sentence is problematic because personal consumption expenditures do include purchased cat food. However, this does not indicate that the Commerce Department has been captured by the animal rights activists. Rather, the purchases of cat food are assumed to equate the relative marginal utilities per dollar of cat food and human food *according to the preferences of the cat's owner*; they will include feline felicity only to the extent that the owner empathizes with kitty.

[32] Dale Jorgenson, Barbara Fraumeni, and their coworkers have made major strides in including measures of human capital in their system of accounts. See for example Dale W. Jorgenson and Barbara Fraumeni, "The Accumulation of Human and Nonhuman Capital, 1948-1984," in R. E. Lipsey and H. S. Tice, eds., *The Measurement of Saving, Investment, and Wealth*, Chicago, Chicago University Press, 1989, pp. 227-282.

Put differently, current attempts to extend the national accounts exaggerate the importance of natural capital and the ignore the role of reproducible, human, technological, and scientific capital. Much is made of the depletion of natural resources, but little is made of the accumulation of scientific knowledge that renders depletion increasingly less important. One example is that of stocks of oil and gas, which are by far the most important appropriable, depletable natural resources. Preliminary estimates of the correction to the U.S. national accounts that would arise from treating depletion of subsoil resources are very small.[33] Another example is copper, which is pointed to as an example of a resource where mining is turning to increasingly expensive grades. What is omitted, however, is the development of new technologies such as satellite communications or fiber optics which make copper less crucial for communications.

A second point concerns the claim in some environmental writings that the capital-intact definition should apply specifically to "natural capital." These writers generally recognize that the capital-intact criterion applies to all tangible capital and not only to natural capital. Yet they argue that natural capital has a higher claim to our national accounts, reasoning that natural capital stocks are lower than the optimal stocks in many countries and additionally that natural capital stocks are generally undervalued. Natural capital has a claim to be maintained intact, they claim, because of risks, uncertainties, and irreversibilities in their use.

These are more questions of religion than science. The fact that natural capital is misallocated means that we should use the appropriate shadow prices but surely does not imply that the appropriate policy is an absolute prohibition on declining natural stocks. Furthermore, risks, uncertainties, and irreversibilities are hardly unique to natural capital. Investments in natural capital such as tree farming hardly seems more irreversible than R&D investments in nuclear power or nuclear weapons; oil drilling is less risky than designing a new jumbo jet; and building new sewage plants seems humdrum compared to running an automobile factory in Russia. Natural capital has no natural monopoly on risk and irreversibility.

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[33] Estimates of the net investment in natural capital are provided in U.S. Department of Commerce, *Survey of Current Business*, April, 1994. The Commerce Department omits the decline of unproved resources, for which an estimate is provided in William D. Nordhaus, "Is Growth Sustainable?" in Luigi Pasinetti and Robert Solow, *Economic Growth*, IEA, Wiley, 1994.

Natural capital and measures of sustainable income

We have spoken about the omitted capital measure as knowledge capital (including human capital) because, in our view, that is by far the most important omission from the national accounts. But what of environmental and resource capital? Surely, they must enter somewhere.

Indeed they do. But they will be appropriately captured in both measures of sustainable income. In the Fisherian approach, if resources are being depleted, natural resource depletion will emerge as slow consumption growth. Slowing growth might be difficult to predict, and it might be gradual or catastrophic, but there is no ambiguity in how declining natural capital will be measured in the Fisherian approach. In the Hicksian approach, declining natural capital can be directly measured (see footnote 33); if a correction for natural capital depletion is omitted, then this will show up as a negative growth in the knowledge measure, A(t). Hence, a deterioration of the environment will appear directly in both measures of sustainable income.

Some reservations

It will be useful to collect some of the reservations about the new approach to measuring income presented here.[34] First, it must be emphasized that measuring the growth of "knowledge capital" is highly uncertain. We have no direct measurement of knowledge capital, so we must infer its growth from the very imperfect measures of total factor productivity (TFP) growth and then capitalize the TFP growth into a knowledge stock. Each of these steps is very imprecise. Nonetheless, they are necessary steps if we are to calculate a theoretically correct measure of sustainable income in the presence of technological change. Moreover, we do have an independent check of the procedure, for the two approaches to measuring sustainable income (the Fisherian and the augmented Hicksian) are quite independent in their assumptions.

Second, the calculations of Fisherian income become increasingly speculative the closer the estimates come to the present. The speculative element arises because consumption is projected from 1993 on in the Fisherian measure. Some readers of an earlier draft, indeed, labeled the estimates as "meaningless" or "operationally worthless" because of this projective nature. While there is some justice in this critique, it applies only to the Fisherian concept and only to recent years. There is relatively little sensitivity of Fisherian income before 1970 to the assumption about post-1993 consumption growth

[34] Many of these points were made by readers of an earlier draft.

(within the range of 0 to 2 percent per year). Moreover, the augmented Hicksian approach contains no projections and therefore does not suffer from this shortcoming. In any case, they are useful ways to view economic history.

Third, sustainability is an insufficient criterion for judging the wisdom of a particular economic trajectory. Hence, this approach is sensitive to the discount rate and a sustainable path may be unacceptable if we accept the hypothesis that we should not discount the distant future to zero (I am grateful to Geof Heal for making this point to me). This is a reflection of the point that to say a path is today sustainable does not mean that it will in fact be sustained. It may be that near-future generations will gobble up so much of their endowments that more-distant generations may experience catastrophic decline. Hence there is no normative content in the designation of a path as "sustainable."

Fourth, some readers have complained that our treatment of natural capital is incomplete and inadequate. We have considered cases where natural capital is a perfect substitute for knowledge, which is clearly unlikely and may be grossly misleading. On the other hand, we have shown above (as in the case of the wayward spaceship) that when appropriate efficiency prices are used the definitions of income used here do capture unviable economic situations. In addition, we have omitted depletion of natural capital and corrections for externalities from our measures of sustainable income. We have done this because there are no reliable measures of depletion of natural capital for the United States that are within an order of magnitude of the conventional estimates of capital accumulation.[35] However, the results should not be interpreted as a Panglossian brief for profligacy or neglect. The estimates provided here may be off base if there are sudden or unpredictable declines in economic activity because of malfunctioning markets or unforeseen events. But the best remedy for avoiding disasters is good science not bad economics.

VI. CONCLUSIONS

This essay has examined the concept of sustainable growth from both a theoretical and an empirical point of view. What are the conclusions?

First, with the rise of concerns about sustainability, economists have begun devising measures for measuring sustainable income. The most common approach, as is implicit for example in the U.N. System of National Accounts, interprets sustainability as keeping capital intact (with a special focus on natural capital). This definition is defective

[35] See specifically the estimates contained in the references in footnote 33.

as a measure of social income except in a stationary economy with no technological change or growth in non-market capital. Appropriate measures are Fisherian income (which is a concept that estimates the maximum sustainable level of consumption) and augmented Hicksian income) which includes the growth of all kinds of capital, including especially knowledge capital).

Second, those who worry about economic growth are concerned whether, as an empirical matter, our economies are consuming more or less than their sustainable incomes. Is this generation consuming more or less than the amount that it should were all generations to consume equally? What about earlier generations? We have constructed two alternative measures of sustainable income for the U.S. that use the appropriate definition, sustainable income. These tentative measures shows that on either measure the U. S. economy has consumed less than its sustainable income for the entire period since the beginning of the last century. However, the true savings rate has definitely declined substantially over the last 2 decades. Thus while the true savings rate is still substantial, we are not saving at the rate the occurred during most of American history.

Appendix. Sources for the Components of Sustainable Income

For data, I use the following:

- Population: These are Census data and are available from *Historical Statistics of the United States* and various issues of *Economic Report of the President.*[36]

- Consumption, Net National Product, Net Foreign Investment, and Net Private Domestic Investment: These are from the Commerce Department for the period 1929-93 and estimates from Simon Kuznets for 1874 to 1929.[37] From 1800 to 1873, real national income per capita is taken from Robert F. Martin, *National Income in the United States, 1799-1939*, National Industrial Conference Board, Inc., New York City, 1939 (see Table 1 in Martin, *op. cit.*). The share of investment is estimated by assuming that gross investment is given by the percentage of realized national production income in manufacturing and construction (see Table 17 in Martin, *op. cit.*). The Martin and Kuznets estimates are linked to the Kuznets and Commerce Department estimates in 1874 and 1929, respectively. Future growth of consumption is taken to correspond to recent estimates of the growth of total factor productivity of 0.5 percent annually in the future.

- Total Factor Productivity: For the period 1874 to 1957, we have used nine-year moving averages of Kendrick's estimates of total factor productivity.[38] These are consistent with the capital accumulation data and exclude productivity growth due to capital quality and human capital because these are excluded from the investment accounts. For the period 1948-89, we have used estimates from the U.

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[36] U.S. Department of Commerce, *Historical Statistics of the United States*, Washington, GPO, 1975; and *The Economic Report of the President and Council of Economic Advisers*, Washington, GPO, various years.

[37] For the Commerce Department's estimates, see *The Economic Report of the President and Council of Economic Advisers*, Washington, GPO, various years. Kuznets' estimates are contained in Simon Kuznets, *National Income and Its Composition, 1919-1938*, National Bureau of Economic Research, New York, 1941 and *National Product Since 1869*, National Bureau of Economic Research, New York, 1946.

[38] John W. Kendrick, *Productivity Trends in the United States*, Princeton University Press, Princeton, N. J., 1961.

S. Department of Labor multifactor productivity measures.[39] The estimates are generally smoothed over a eleven-year period to remove cyclical influences, temporary shocks, and measurement error.

Discount rate on consumption: The estimate of the annuity rate on consumption takes the recent post-tax return on capital of 5 percent per year (inflation corrected).[40]

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[39]Bureau of Labor Statistics, *Multifactor Productivity Measures, 1993*, Release, February 14, 1995.

[40]These are consistent with the post-tax return on consumption in most long-term empirical estimates, such as Dale W. Jorgenson, "Investment and Economic Growth," *The Simon Kuznets Lectures*, Yale University, November 11-13, 1994; Warwick J. McKibbin and Jeffrey D. Sachs, *Global Linkages : Macroeconomic Interdependence and Cooperation in the World Economy,* Washington, D.C., Brookings Institution, 1991. For a compilation of recent estimates, see W. D. Nordhaus, *Managing the Global Commons*, MIT Press, Cambridge, Mass., 1994.

Table 3

Alternative Savings Rates

[As percent of net national product or sustainable income]

	Income Concept		
Period	*NNP*	*Augmented Hicksian*	*Fisherian*
1800-1993	na	na	30.4
1874-1993	9.4	na	33.0
1950-1993	8.5	28.3	28.4
1980-1993	4.5	11.8	17.9

na = not available

na = not available.

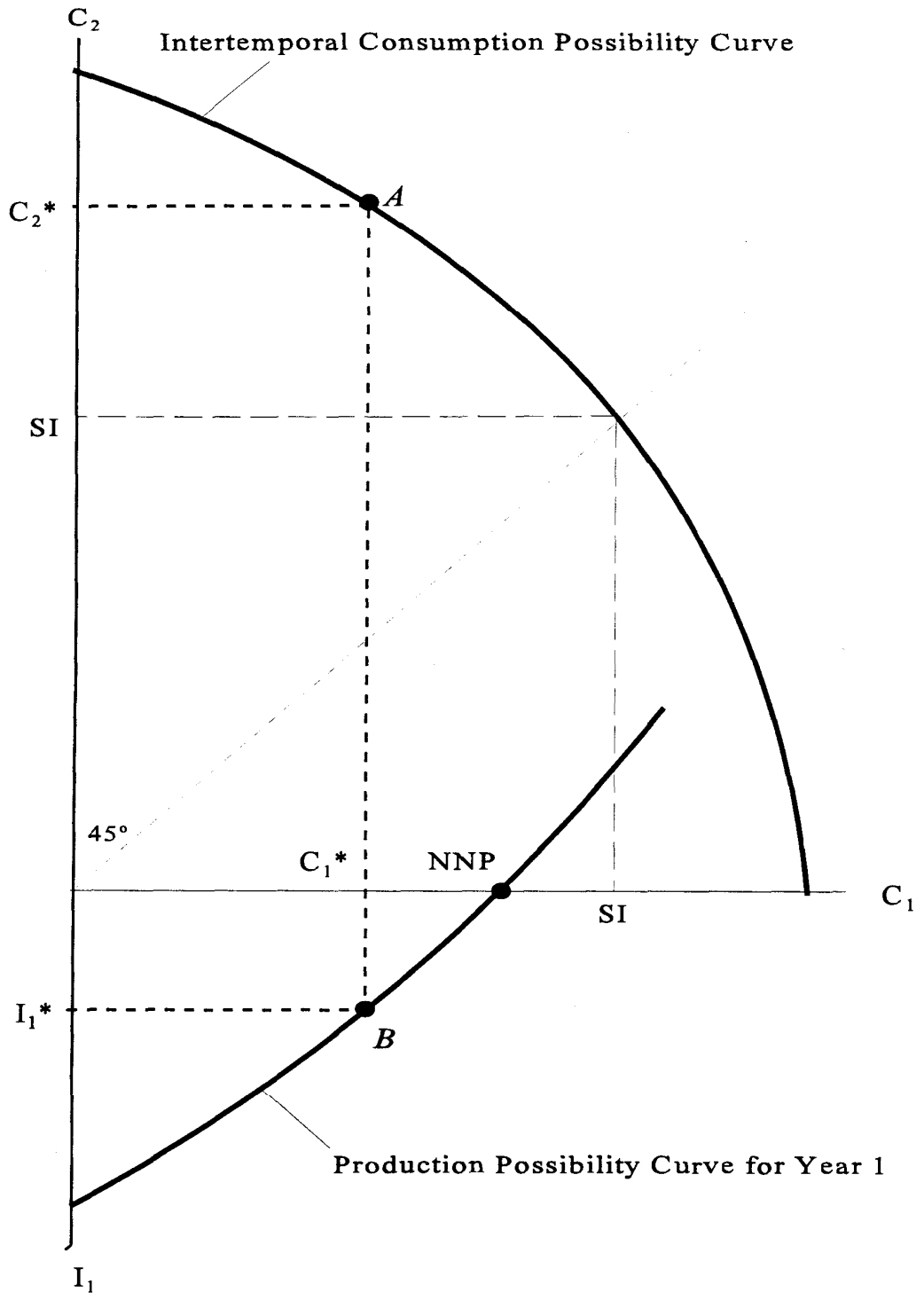


Figure 1. **Net National Product and Sustainable Income**

Lower diagram shows tradeoff in first year, with consumption and investment C_1* and I_1* and conventionally measured saving of NNP - C_1*. Upper diagram shows intertemporal tradeoff. *SI* measures sustainable income at which $C_1 = C_2$. Note that saving using the sustainable income concept is *SI* - C_1*, which will exceed conventional saving when economy has technological change.

Figure 2

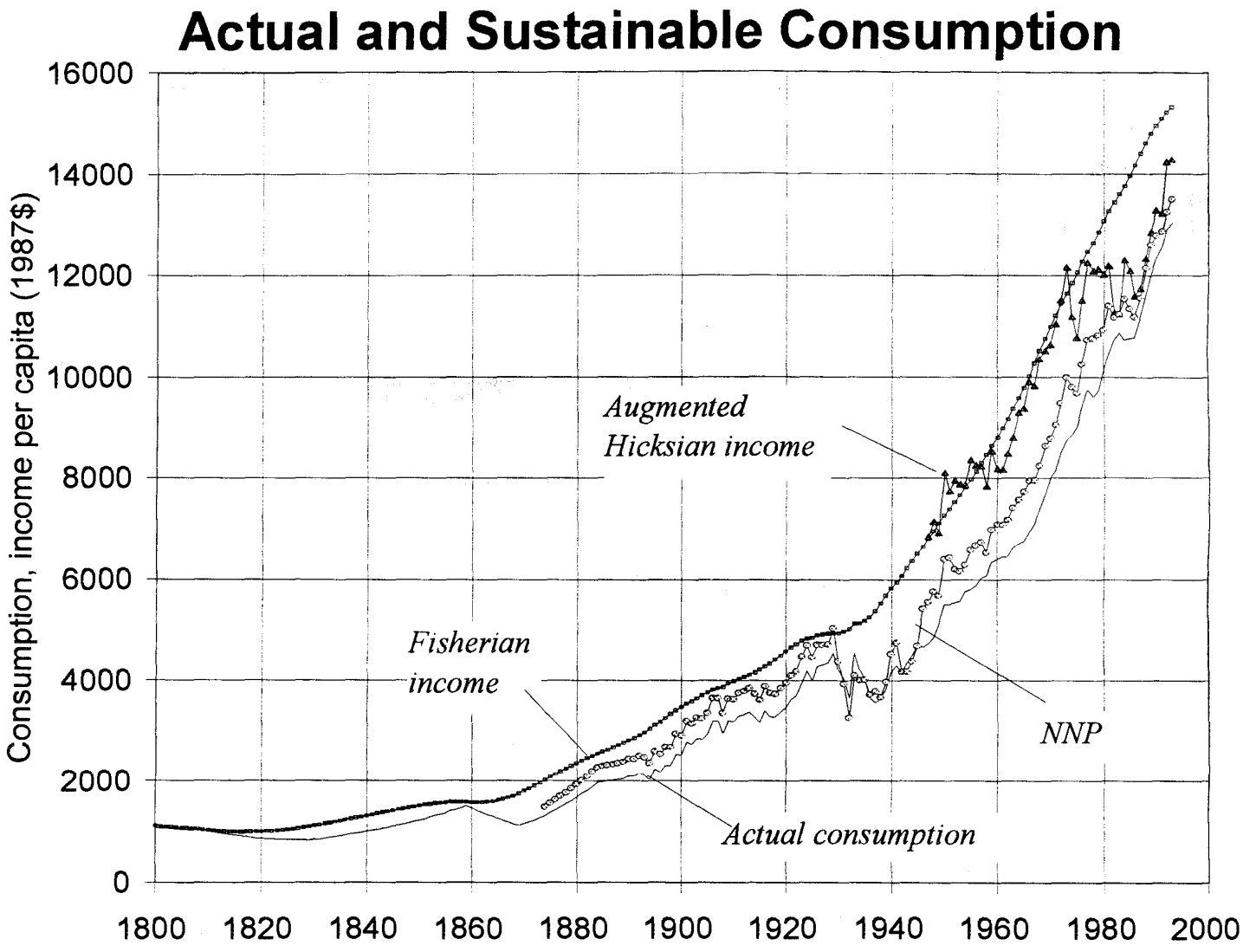

Actual and Sustainable Consumption
Consumption, income per capita (1987$)
16000
14000
12000
10000
8000
6000
4000
2000
0
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
Augmented Hicksian income
Fisherian income
NNP
Actual consumption

Figure 3

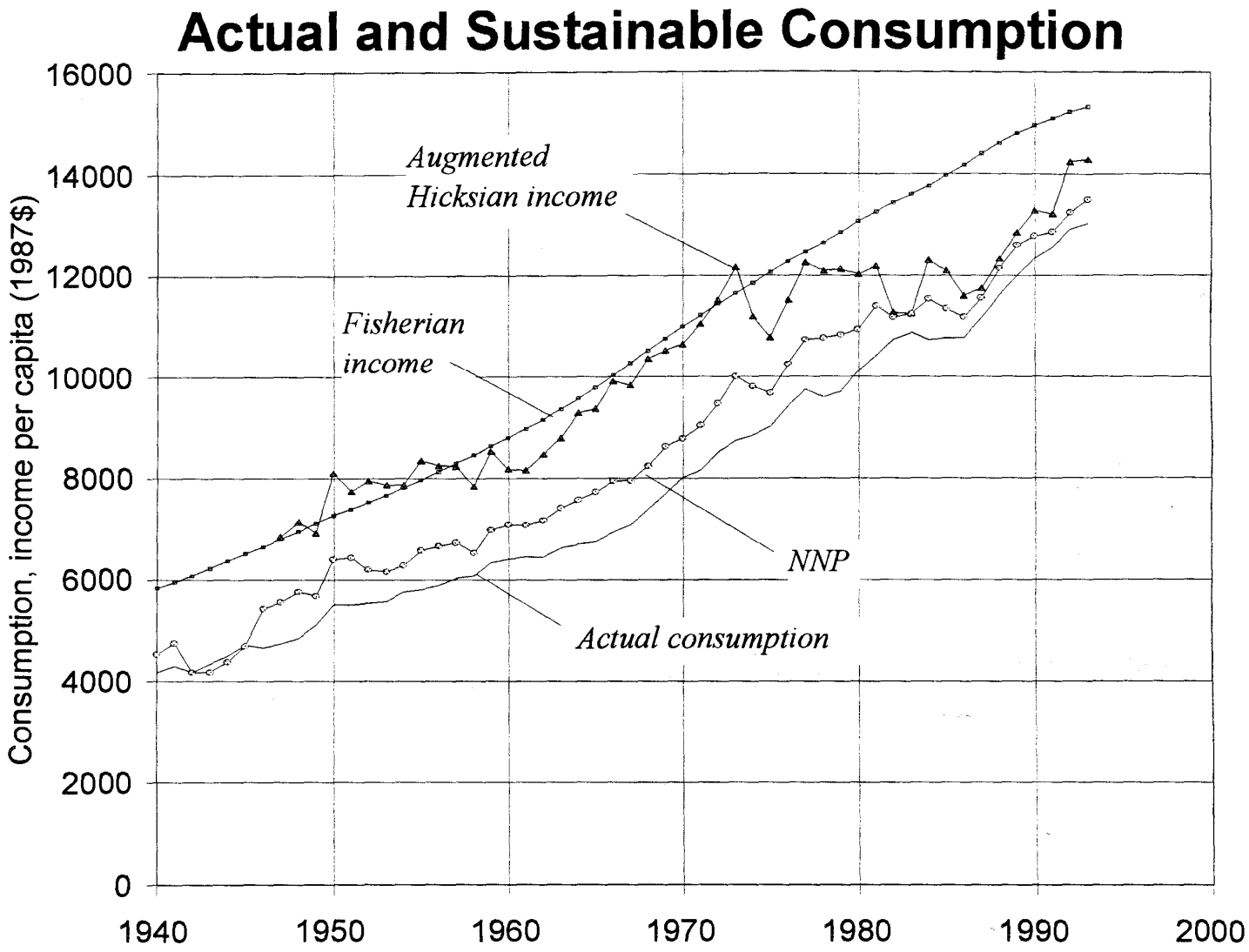

Actual and Sustainable Consumption
Consumption, income per capita (1987$)
16000
14000
12000
10000
8000
6000
4000
2000
0
1940
1950
1960
1970
1980
1990
2000
Augmented Hicksian income
Fisherian income
NNP
Actual consumption

Figure 4

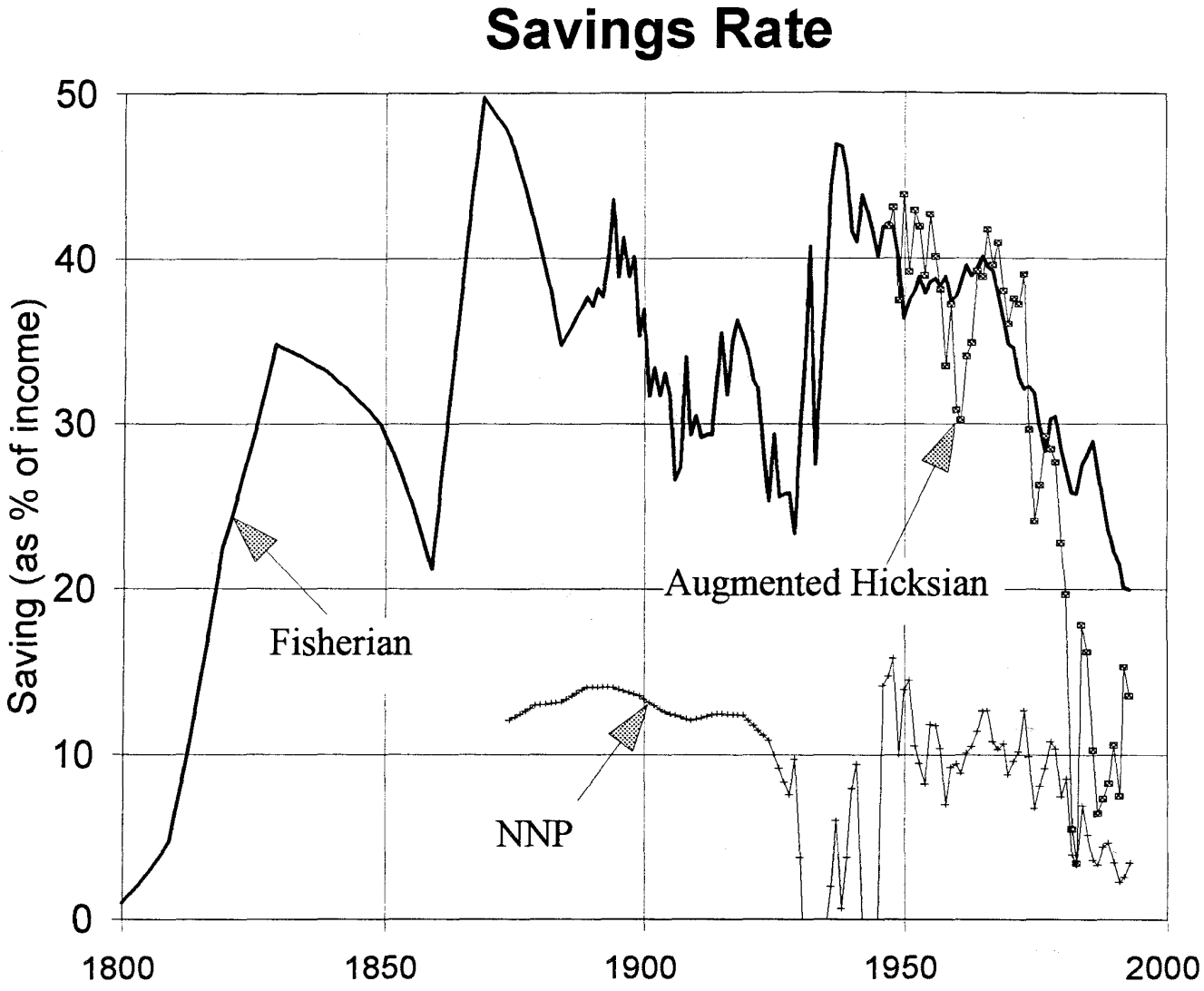
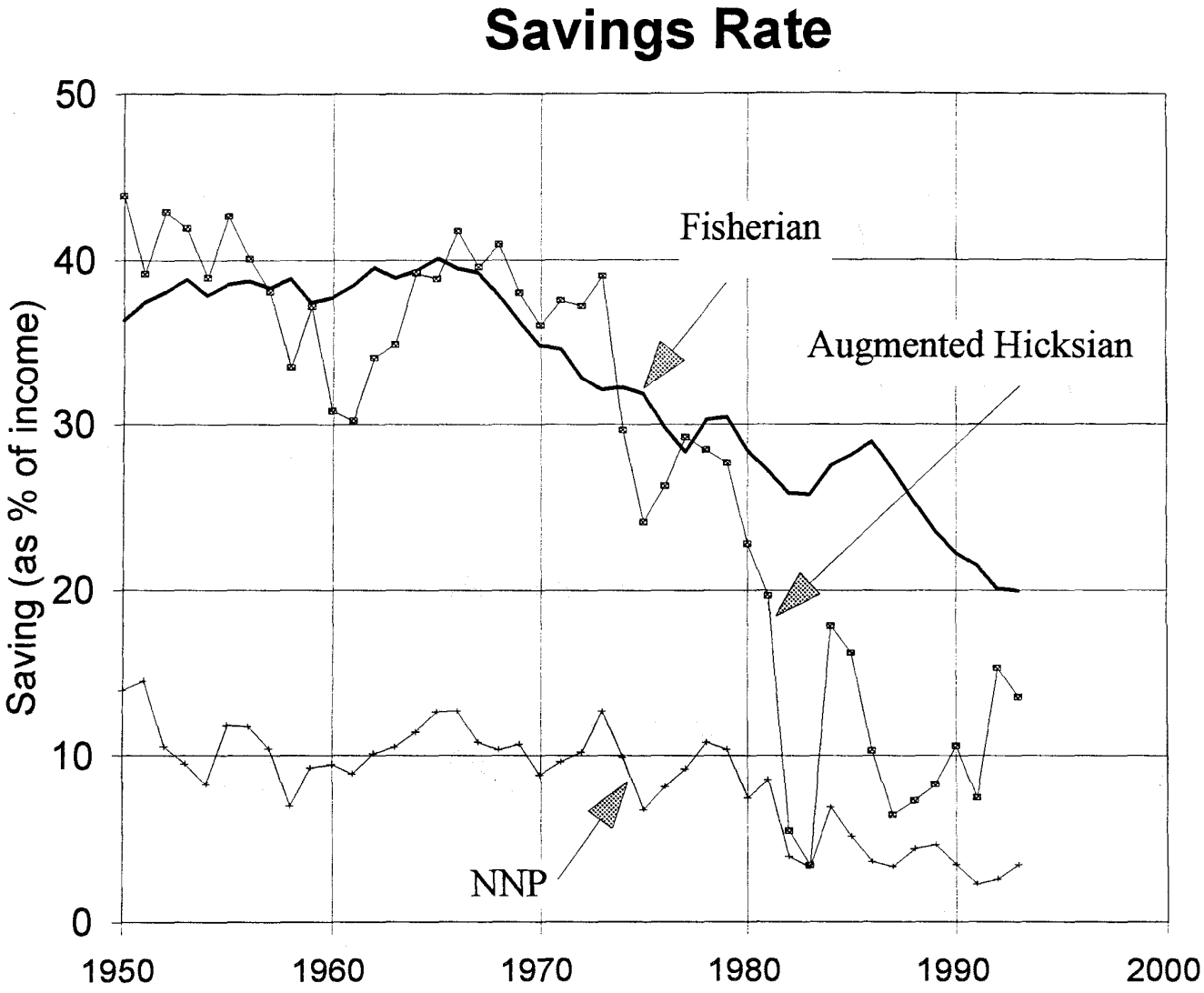

Savings Rate
Saving (as % of income)
50
40
30
20
10
0
1800
1850
1900
1950
2000
Augmented Hicksian
Fisherian
NNP

Figure 5


Savings Rate
Saving (as % of income)
50
40
30
20
10
0
1950
1960
1970
1980
1990
2000
Fisherian
Augmented Hicksian
NNP