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How well do we measure development?

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Sustainable growth: do we really measure the challenge?

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Abstract

Macro measurement is a long and arduous process that impinges upon the system of national accounts. The challenge it raises is driven by the demand of economic policy. In present time the need will arise with sustainable growth that mixes environmental concern and development policy. It calls for no less than a sea change in national accounting, from a system of income and expenditure accounts focused on GDP to a system of wealth accounts. The latter emphasizes an extended concept of capital, encompassing all assets that contribute to social welfare and an associated measure of "genuine" saving.

The paper goes on analyzing the problems raised by measuring the different types of capital that are either ignored or little treated as such, according to the accepted rules of national accounting. However intangible assets are as large as productive fixed capital in developed countries and are the most important factors of growth in the knowledge economy. Besides, natural capital must be priced according to its scarcity as source of primary resources, absorber of greenhouse gases and conservatory of biodiversity.

Because the very nature of those types of capital leads to measuring them as the discounting value of future rents, the choice of discounting rates is critical to the valuing process. The discount rate is as much important for valuing the social commitment of pensions, as it is for estimating the cost of the depletion of non-renewable resources and the damages inflicted by man-made production of carbon dioxide.

The paper shows that the process of valuing the different types of capital and estimating their substitutability in producing social welfare is plagued with radical uncertainty. There are multiple paths of growth whose sustainability is open to question, because there are "unknown unknowns" in the interactions between economical and ecological factors that might be beset by disruptive highly non-linear feedbacks. Therefore the choice of discount rates is deeply ethical and must pertain to a generalized precautionary principle, since it involves the fate of future generations. This principle is validated while there are possible situations of unlimited downside risk exposure. Societies facing catastrophic crisis of unknown probability must debate right now how to organize collective decisions for undertaking the right policies.

Mots clés: climate change, discount rate, genuine saving, intangible capital, natural capital, sustainability.
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Introduction: stages of progress in macro measurement

From the 17th to the 19th centuries there were numerous individual attempts in estimating national income. They were forerunners in macroeconomic and demographic quantifications. However they stayed individual enquiries aiming at evaluating and comparing the strength of countries, largely inspired by mercantilist doctrine. In Great Britain William Petty (1623-87) was the pioneer in 1665, followed by Gregory King (1648-1712). In France the pioneer was Boisguilbert (1646-1714). In his work "*le detail de la France*", he depicted a very pessimistic assessment of the Kingdom under Louis the 14th, because of its extremely unfair fiscal structure.

Those scholar searches had never become analytical tools in economic policy. In the liberal era of the 19th century, they even attracted less attention. The economic significance of macro magnitudes was even doubted after the middle of the century. Economic adjustments in the business cycle were understood to stem from market interactions between individual agents without the need of public intervention. Even World war I did nt change the conception of economics.

National accounting and macroeconomics are the joint offsprings of the Great Depression and World War II. The Great Depression was crucial with its sustained mass unemployment, which spawned Keynes's General Theory. World War II gave the definite impulse with the huge growth in public receipts and expenditures and the imperative to mobilize and re-allocate resources at the national level. Therefore the rationale for the measurement of intertwined economic aggregates in determining the overall level of economic activity had become overriding.

Therefore macro measurement emerged as a tool of economic policy in the 1940's.Two basic works in 1940 induced its development for macro management and for interpreting history. They were J.M.Keynes's "*how to pay for the war*" and C.Clark's "*the conditions of economic*

progress". A host of authors followed led by S.Kuznets who pioneered quantitative economic history on the one hand, J.Meade and R.Stone who contributed to standardize national accounting on the other hand. With Keyne's suggestion, they published together a seminal article in the Economic Journal (May-September 1941): "*The construction of tables of national income, expenditure, savings and investment".* The article presented the structure of national accounting they had elaborated together. It was the cornerstone for the memorandum of 1945 published by the UN in 1947. Therefore national accounting, Keynesian macroeconomics and regulation of aggregate demand are the three pillars of macro measurement.

Adjacently but independently of the investigation on national accounting, Wassily Leontiev introduced input output analysis at Harvard, starting in 1932. In 1941 he gathered the result of years of research in a book published by Harvard University Press: "*The structure of the American Economy 1919-1929: an empirical application of equilibrium analysis".* However the input-output table was not integrated in the main body of the standard national accounts. It was used by the BLS which designed the table for year 1947. But the work terminated with the Korean War in 1950.

After 1950 there was a long route to standardization, international comparability and finally unification in the 1968, and more completely the 1993 system of national accounts under the auspices of the UN. The main problems to overcome were the scope of economic activity in estimating GDP, the adjustment for price changes to exhibit volume magnitudes in estimating GDP growth, the purchasing power parity converter (PPP) to measure real GDP levels at international prices in providing international comparability.

GDP was understood as the crosscheck of three approaches of national income in what emerged as a development of flow accounts. On the demand side, GDP was defined as the sum of final expenditures. On the income side it was the sum of wages, profits and rents. On the production side it was the sum of the sectoral value-added. The standardized criteria designed by Richard Stone were pushed forward by Milton Gilbert in the OEEC. He persuaded the statistical offices of member countries to adopt them as the basis of and sharing to implement the Marshall Plan.

However the Anglo-Saxon view did not prevail for a very long time. The USSR had a much more restrictive conception of economic production based upon material output. Their accounts were grounded on material balances. Apart from this view related to central planning in a society alien to market economy, there was a French way. French national accounts used also more restrictive concept of production, albeit more extensive than the Soviet one, regarding the problem of value imputation of non-market services. Besides the French system used input output tables for a more detailed analysis of the production structure and described financial transactions. Furthermore the system described the behaviour of groups of economic agents, which articulated operating, transfer and capital accounts. The compatibility between national aggregates and agent accounts was realized in the "*tableau économique d'ensemble*".

It was not before 1968 that reconciliation between the French and the Anglo-Saxon systems began under the aegis of the UN. The French system enlarged its concept of production to encompass the production of administrations. The Anglo-Saxon system opened to agent accounts. Much discussion that has lasted for years has arisen on the way to deflate nominal values. Competing indices can be used. The introduction of hedonic prices to make allowance for quality changes in commodities has never gained universal approval.

The problem of price changes over time has a dual mirror with the PPP converter to make space comparison. The tricky problem is the definition of international prices that requires the definition of an international standard basket of goods and comprehensive international

surveys to measure the prices of identical goods in a large array of countries. The combination of PPP designed to eliminate inter country differences in price level and volume estimates over time has given rise to space time comparisons. The first studies were done by Milton Gilbert and Irving Kravis in 1954, who compared real expenditure levels in seven Western European countries and the US. Later on Kravis, Heston and Summers launched in 1968 an international comparison project in the university of Pennsylvania, going on to this day. The UN Statistical Office has extended it and the OECD has proceeded to comparisons on a regular basis;

Meanwhile the most outstanding use of time space comparisons in GDP has been the monumental work of Angus Maddison in the OECD, who built series of world and main regions GDP as far back as year 1000, in order to assess historical stages of economic development, unequal distribution of world income, catching-up and relative declines.

Building on those earlier foundations, there have been significant advances in overcoming the many problems involved in developing the system of national accounting in the direction of understanding better the linkages between social welfare and economic activity, at least the aspect of social welfare that can be approached in economic value. Let us call it economic welfare.

National income and social welfare: a perennial problem

In his "*Economics of Welfare*", Pigou formulated explicitly the question in 1920. Can national income (NI) or national product (NP) be considered an indicator of economic welfare? To do so economic values must be interpreted in the framework of utility theory. An alternative solution favoured by Kuznets was considering the final objectives pursued by economic activity.

Each approach faces formidable obstacles. The utility approach tries to use prices to integrate measures provided by national accounting in welfare. But the relationship between market prices and marginal utility is highly problematic, especially if one wants a cardinal measure of utility to aggregate personal preferences, not less because the search for comparison of interpersonal utilities is rife with insuperable difficulties. Already Alfred Marshall, in his 1890 *"Principles of Economics",* doubted that it was possible to apprehend utility value beyond the vicinity of market prices. The alternative approach is not that much promising for the purpose of an aggregate measure of economic welfare, because it has to spell out what the final objectives are and to look for multiple "objective" standards of physical measure, whose integration in a single aggregate is either impossible or quite arbitrary.

Admitting that it is impossible to get rid of prices, Pigou thought that it is vain to hope for an absolute measure of welfare by NI, but that something can be done if one restrains one's ambition to *measuring the variation of NI* under restrictive assumptions. If the tastes of individuals and the distribution of their purchasing power among a group of people is fixed between dates t and t+1, the economic welfare of such a group has increased between t and t+1 if the total income of the group has increased. It can be applied to nation and measured by NI variation, because one can presume that structural underlying preferences and income distribution do not change much in the short run.

However, if one is interested in social policies aiming at reducing inequalities and improving the well- being of lower income citizens, as a condition for a better social cohesiveness of the nation, a longer perspective is needed. Not only income distribution can change, but a

narrowing in income inequalities might be considered as a most effective means in improving social welfare.

Hicks entered the debate with a famous article published in *Economica* (May 1940) on "*the valuation of social income"*. Focusing on the budget of an individual with unchanged tastes, who consumes quantities (q) of different goods (i) valued at prices (p), such an individual is in a better situation in t+1 than in t if: $\sum p_{t+1}q_{t+1} > \sum p_{t+1}q_t$. The individual could still afford acquiring the basket q_t but she prefers q_{t+1}. Conversely the individual is in a better situation in t if: $\sum p_t q_t > \sum p_t q_{t+1}$. But the ranking of both situations is ambiguous if:

$$\sum p_{t+1}q_{t+1} < \sum p_{t+1}q_t$$

Hicks extends the income comparison to the whole society. If the first two inequalities are satisfied together, the assumptions of unchanged tastes cannot be held. Even if t+1 is a better situation than t, applying it to the whole society requires the admission that it is impossible that everyone can be put in t in a situation as good as in t+1 by any redistribution of quantities acquired in t.

After Hicks's contribution, many attempts were made to find out welfare indexes that could escape any ethical criteria in the possible reallocation of goods. However in further research, Hicks admitted that such indexes do not exist. Following an opposite approach, Amartya Sen in article ("*real national income*") published in the *Review of economic Studies* in February 1976, used an ordinal framework. He showed that the marginal dollar possessed by a poorer person has a higher marginal value than the same dollar possessed by a richer one. Therefore it is necessary to account for the distribution of income, the structure and the size of the population according to judgments that explicit ethical values.

With this elusive theoretical foundation, what can national accounting do to measure economic social welfare? One should put up with a watered-down view of welfare, which assimilates the satisfaction of needs with the final objectives of economic activity. The main questions for measuring are the following: how to deal with the public services that are not directly dedicated to individuals, the so-called defensive public expenditures? How to deal with household expenditures that are induced by the constraints of urban life? How to take account of environmental costs and expenditures?

The 2009 Report by the Commission on the Measurement of Economic Performance and Social Progress, chaired by Joseph Stiglitz, is the latest and most comprehensive contribution. It follows suit in a pervading debate and acknowledges a string of definite choices made in the system of national accounts (SNA) since the 1970's.

In the 1993 SNA it is clearly upheld that GDP is not a welfare indicator. However drawing from the long theoretical tradition from Pigou and Hicks, the SNA observes that there is a relationship between variations in production or in total consumption and variations in economic welfare. Which prices should be used to calculate the aggregates so that they express the relationship better? When prices change, the cost of living index must be equal to the amount that a consumer income shall be modified, so that she is in the same economic situation as before the price change. This is the theoretical cost of living index. It can be demonstrated that, if consumer preferences are homothetic and their utility function quadratic, the Fischer index (a geometric average of Laspeyres and Paasche indexes) coincides with the theoretical index. However, if consumers have heterogeneous preferences, the volume of final consumption does not approximate economic welfare. Two obstacles remain: the aggregation of preferences and the impact of externalities. What is the best that can be done anyway if one wants a relevant aggregate?

In 1970, William Nordhaus and James Tobin wrote a seminal article ("*is growth obsolete?*", reprinted in Milton Moss ed., *The measurement of economic and social performance*, Columbia university Press, 1973) that launched a number of further studies. That work was undertaken outside the framework of national accounting. It was not before the 1993 revision that some results were embodied into the system. For the purpose of this paper, we focus on defensive public expenditures and environmental externalities.

- **Defensive public expenditures.**

Defensive public expenditures are not direct services to households and do not enter present-day total consumption because they produce flows of services that span long periods of time. They must be dealt as public investments. They are basically public investments of three kinds. Security expenditures (police, prisons and army) are investments in social capital. Expenditures to expand and improve the health system are investments in human capital. Environmental expenditures to mitigate and accommodate climate change, to substitute to the depletion of fossil energy resources and to preserve living species diversity are investments in natural capital.

The impact of economic activity, which downgrades the quality and the quantity of those assets, shall be dealt as generalized capital depreciation and depletion of the stock of capital that involves a reduction in net national income.

However there are defensive expenditures, imputed to households, which cannot be registered as investments. An example is the measurement of commuting expenditures that constrain transports due to urban life. They produce services that use capital and labour. But they are not investments themselves. They should be included in an extensive definition of household production that is not paid by firms in the present social organization. It is therefore a transfer of added value from households to firms.

- **Environmental services**

As far as natural capital is taken as a free good by economic agents, the social costs entailed by its depletion are not imputed to economic activity. There is an uncontrolled and unregistered diminution of economic welfare. Therefore the losses due to the deterioration in the quality of environmental services due to economic activity, must be measured, primarily pollution. They are losses in the value of natural capital.

However streams of environmental services, while part of economic welfare, are not contained in final consumption, because one does not know the elasticity of substitution with economic goods to aggregate them with market services. In this paper they will be taken as a separate variable, entering the cardinal economic welfare function aside final consumption, the elasticity of substitution being an unknown parameter.

- **From social welfare to economic sustainability**

Therefore the way forward lies in widening the concept of capital to the whole domain of assets concurring to the maintenance and expansion of economic welfare for the whole society over time. This is essentially a dynamic concept o*f sustainability*.

In such an all-encompassing conception of capital, public services are non-rival and non-exclusive public goods that are produced by tangible and intangible assets, which can be used by all economic agents. Those collective assets are owned by society at large.

The advantages of enlarging the concept of capital for the study of development are considerable. One can analyze systematically the relationships between income and asset values. For instance, how much the capital invested in health impinges upon labour

productivity and real income growth, feeding a sustained virtuous circle? Conversely how much pollution depreciates human capital via health deterioration? While environment is being deteriorated, one must distinguish between the initial impact, which creates losses affecting unequally the capital account of economic agents and the investments to repair the losses that are current expenditures appearing in flow accounts.

The change of perspective brought about by the sustainability approach raise questions about the intellectual property of capital, which in turn induce accounting reallocations. Items that had been traditionally treated as intermediary inputs should be reclassified as investments in capital. This primarily the case of R&D expenditures, formerly an intermediary input and lately reclassified as an investment in intangible capital in the 2008 system. It is also the case of mining prospection, which generates new knowledge in subsoil primary reserves.

Therefore sustainability is the new frontier in development. For decades capitalist accumulation was based upon the prerequisites that the use of non-renewable resources was cheap, that the stock of non-used resources was free and that growth was unlimited. This crude model has become less and less relevant, all the more than the huge development of services has emphasized the paramount role of intangible capital as sources of productivity. Meanwhile the exhaustion of natural capital has become the focus of oligopoly rent appropriation and of geopolitical maneuvers for the security of supplies. Furthermore the looming future costs of climate change are so uncertain and so threatening in worst-case scenarios that the future of humankind as we know it is at stake.

The concept of sustainable growth is being defined and developed with the ambition to be all-encompassing, in order to deeply reform economic policies. Sustainable growth will entail a revolution in economic thinking, in accounting, in government policies and in the organization of finance. Broadly, sustainable growth takes the long-term protection of the environment and therefore the welfare of future generations within the growth regime. A flow accounting framework aiming at measuring and enhancing GDP growth must be completed with a stock flow accounting aiming at measuring genuine capital (e.g. total wealth), which is the resource base of producing future social welfare, and thus enhancing total wealth accumulation.

The challenge of sustainability: from income to wealth accounts

Early punctual attempts to measure national wealth were made in the 1950's. They were presented and discussed in the IARIW conference of 1957. The first long series for the US (1945-58) are due to Raymond Goldsmith's research published in 1962 and 1963. Sectoral accounts covered tangible and sub-soil assets. Intangibles were limited to financial assets, everything being calculated by the method of the perpetual inventory. Those attempts were too narrow in scope and too uncertain in measurement to consider integration in the normalized system of accounting.

In the mid-1960's John Kendrick undertook a vast historical study, published in 1976, on total capital stocks in the US, including human capital and R&D. He included intangible investment in education, health and social mobility. He counted R&D separately. Kendrick's result was startling. He showed that the value of human capital equated the value of all other assets as soon as 1929 and was 15% higher in 1969. The consequence is that standard national accounting, and worse private firm accounting, grossly underestimates factors of growth.

Theoretical motives for improving the measurement of capital arose in the 1980's with the formal modelling of endogenous growth theory undertaken by Romer and others. With the work of Aghion an Howitz, the approach broadened to embody Schumpeterian innovation. However the integration of capital changes due to investments that improve productivity remained parsimonious. Software was included, but the integration of R&D expenditures met a strong resistance from national accountants. There were also problems for mining and oil exploration expenditures. They did not represent the value of mines and oil fields computed from the value of the rent after subtracting all costs, including the depreciation of exploration expenditures. More generally the principle of valuing an asset by discounting the series of expected future streams of income met the reluctance of accountants about the elusiveness of expectations and the arbitrariness of the discount rate.

Objections, pitfalls and obstacles are not surprising. Wealth accounts involve the measure of assets and liabilities. Measuring wealth is a tricky endeavour. Wealth items extend under considerable and differentiated periods of time. Two related problems appear: how valuing wealth? How articulating stock and flow accounts? As we know it, an economic measure is defined in terms of value, e.g. the social contribution of any activity using available resources. However taking account of stock variables mixes values that have different status in measurement: realized value against money payment, imputed value, discounted (e.g. anticipated) value, substituted value (opportunity cost). Disparity in status means that integrating income (flow) accounts and wealth (stock) accounts is not a task that can be done without conventions and approximations.

Integrated wealth accounts have only been considered in the 1993 system of national accounts. In his big history of national accounting, published in 2002, André Vanoli explained that, besides flows pertaining to economic operations normalized in national accounting, other flows must be described in two accounts of accumulation. The one is the account of *other changes in asset volumes*. It aims at changes in the substance of wealth that does not stem from production, primary income, capital transfers and variation in asset prices. The other is the account of *asset reevaluation*. It highlights real capital gains or losses due to variation in specific prices relative to changes in the general price level.

While those estimates have been made, it becomes possible to establish a link between saving and change in the net value of wealth:

Net saving = Δ(net real value of wealth) – net receipts in capital transfers – other net changes in asset volumes – real gains or + real losses in holding wealth

The World Bank is the institution that has ploughed deeper into the task of measuring total wealth as a tool to assess the sustainability of growth paths in advanced and developing economies. It has drawn upon a pioneer work by Pearce and Atkinson, "*capital theory and the measurement of sustainable development: an indicator of weak sustainability"*, published in 1993 by the review of Ecological Economics. From a first report in 1995 ("*Monitoring environmental progress"*) to its 2006 major report ("*Where is the wealth of nations? Measuring capital for the 21st century*"), the World Bank has explored a methodology and empirical investigation aimed at changing development policies. But now national governments must take over.

Development policies can be linked to sustainability, as much as they are interpreted as generalized portfolio management strategies. To implement such strategies, the government of a nation must redeploy its statistical apparatus in a collective effort to estimate the changes in the total wealth of the nation in size and composition. It is a major effort, as demanding as the one that led to the foundations of national accounting between 1940 and 1950. Only a

deadly challenge that requires a mobilization of national resources can induce government to undertake a collective effort to embark in a policy shift that requires the shaping of new policy tools. World War II was that immediate challenge and the cooperation of democratic nations was vital.

Today's problem lies in a world challenge whose time span is entirely different. Climate change, depletion of tropical forests and oncoming scarcities in water and fossil resources are long-term challenges that carry the threat of extreme events decades ahead or in the next century. Therefore the threat involves future generations even more than present ones. The stake are long beyond the horizon of the issues dealt with in the political debate of elective democracies. It is so because the ecological system embodies a lot of inertia; but may become vulnerable to uncontrollable diverging feedbacks if unknown thresholds are overstepped. Therefore humankind faces a world of unknown unknowns that nonetheless depend on its own behaviour in the next few decades.

Shall governments embark in a policy of massive investments in radical innovation at the expense of present and near-term consumption, in the hope that new renewable energy investments will make environmental and economic goods more substitutable in the longer term? Or shall they wait in the hope of getting more information on climate change developments and natural capital depletion at the risk of letting irreversible damage occurring? To better appreciate the dilemma, governments must increase their knowledge on the processes that lead to sustainability or unsustainability of their economies they have the duty to lead and regulate in highly alternative scenarios.

Furthermore advanced economies have been severely weakened by the ongoing remnants of the financial crises. The immediate responses to the crisis have massively transferred debt burdens and attached solvency risks from the private financial sectors to the public sectors. Meanwhile, population ageing has piled up contingent liabilities for the future that have been aggravated in many countries where pension funds suffer deep under funding. Nonetheless, facing the environmental challenge will require a sustained effort in public investment to alter both the size and composition of total capital, in order to make it less vulnerable to future resource shocks and catastrophic climate events. It follows that sustainability of public debts requires credible programs of consolidation in the short to medium term that do not jeopardize the investments required for future sustainable development in the whole economy. Nonetheless public finance sustainability is the priority of the next decade in many advanced countries whose environmental choices are also crucial for overall economic sustainability in both developed and developing countries. Because all policies dedicated to sustainability stand on the simulation of uncertain future paths, they meet common measurement problems. It is why this paper will try to highlight the stakes of public finance sustainability before moving to the more general question of sustainability in growth regimes.

- **Definition of total wealth and sustainability**

Development depends on total wealth, e.g. produced, human, social and natural capital. Sustaining total wealth is the key for viable growth regimes. The different forms of capital are defined in the following way:

Produced (tangible) capital= equipment + structures + urban land
Intangible capital= human capital +institutional infrastructures + social capital + net foreign financial assets
Natural capital= subsoil assets + Timber resources + non-timber forest resources +protected areas + crop land + pasture land

The sum of the three components is real wealth of the nation. In the present state of our knowledge it is far from being comprehensively measured. Only a massive statistical effort mobilizing government resources and an international coordination can make decisive progress. Future growth prospects are linked to changes in real wealth. Changes in real wealth has been named adjusted net saving (or *genuine saving*). As shown above, there is a weak link between changes in real wealth and variation of future well-being, e.g. of social welfare conditional to adjustments for defensive public expenditures, household production and environmental services. A strong link would require restrictive assumptions for permanence of individual preferences, income distribution and relative prices reflecting marginal utilities. Box 1 describes the formal derivation of the sustainability condition from the social welfare function under the proviso of strong sustainability. However the formal derivation of the sustainability condition from welfare economics, even if it cannot directly give rise to measure, helps understand the meaning of the approximations that one is led to make in forging a measurement methodology. Box 1 sums up the derivation of the sustainability condition from a cardinal social welfare function.

If the different types of capital that make the productive base of the economy in a general ecological and economic sense can be measured, the variation of total wealth per capita is the sum of the growth of total factor productivity and the growth in the aggregate growth in the volume of the different types of capital (box 1).

Box 1. From social welfare to economic sustainability

As explained in the discussion on the relationships between national accounting and welfare economics, environmental services are not perfectly substitutable with private consumption in a cardinal social welfare function. The limited and highly uncertain elasticity of substitution between private consumption and environmental services is modeled as in a recent contribution of Olivier Guéant, Roger Guesnerie and Jean-Michel Lasry ("*ecological intuition versus economic reason"*, May 2010)

Definition of the welfare function

V is a social welfare function in continuous time, function of two variables:

C(τ) an aggregate of extended private consumption embodying the value of social services that are directly allocated to households and consumed in the same period, recalling that non-environmental defensive expenditures are accounted as public investment in human or social capital.

E(τ) the services of environment that flow from natural capital

V is an inter temporal cardinal function:

$$V(t) = \frac{1}{1-\eta}\int_t^{\infty} U[C(\tau), E(\tau)]^{1-\eta} e^{-\delta(\tau - t)} d\tau$$

δ is the pure rate of time preference and η is the rate of relative risk aversion

The imperfect substitutability between private consumption and the services of environment is described by a CES function whose limited elasticity is σ:

$$U[C(t), E(t)] = [C(t)^{\frac{\sigma-1}{\sigma}} + E(t)^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}}$$

Criterion of sustainability

The strong criterion of sustainability is that V is not decreasing:

$dV/dt \geq 0$

The final goods and services providing utility, either from consumption or from the environment, are produced by combinations of all types of capital defined above according to the best available technology. The different types of capital are reduced by their used in production and increased by investment (productive and human capital), by natural repletion if renewable (forests) or irreversibly reduced by extraction if non-renewable (subsoil fossil resources). The output generated by the combination of all types of capital is compounded of consumption, services of environment and investment in reproducible capital. The allocation of output depends on the adjusted rate of saving (genuine saving) and the public rule that makes environmental services available in specific quantities. One supposes that the allocation mechanism is such that *V is not an explicit function of time.* It follows that the stocks of the different kinds of capital in t+1 are determined by the stocks in t and by the permanent allocation mechanism. This assumption is not so benign since it abstracts from uncertainty as far as the allocation mechanism is concerned.

Under this assumption one can proceed from period to period and determine in principle the entire future course of capital stocks of different types and flows of consumption and environmental services. If there are n stocks of capital K_i at time t (i=1, ,n), the values of the macro variables in the economy are determined at all future times $\tau > t$. it follows that U is determined for $\tau \geq t$ and V(t) is determined as well. One can write:

$V(t)=V[K_1(t), K_2(t),..,K_n(t)]$

The strong sustainability condition requires:

$$\frac{dV}{dt} = \sum_{i=1}^{i=n} \left(\frac{\partial V}{\partial K_{it}}\right)\left(\frac{dK_{it}}{dt}\right) = \sum_{i=1}^{i=n} p_{it} I_{it}$$

Where p_i is the contribution of the ith type of capital to inter temporal welfare, e.g. the shadow price of capital K_i and I_i the net investment in that type of capital.

The strong sustainability condition means that, if capital is valued at its "fair price", the variation of social wealth in t is equal to the variation of inter temporal social welfare. *The criterion for sustainability is that real wealth is not decreasing, e.g. that genuine saving is ≥0.*

This condition is quite general. It does not require that the welfare function has the analytical form chosen above to show how environmental services can be treated separately from household consumption. The absolute value of V has not to be computed. One has to compute the change in real wealth. However for strong sustainability to apply, the prices with which the elements of wealth must be computed are shadow prices. They are not prices one can observe. They are the prices that would prevail if all types of wealth were commodities traded in competitive markets under perfect foresight. Because many types of capital are not traded commodities at all, they are partly calculated as *discounted rents*, e.g. *the price that must be paid for the scarcity of the resource.* It is where measurement problems become tricky.

Furthermore, in the above equation, shadow prices are measured in units of utility per unit of capital. This is not convenient for empirical use. One type of capital that has an observed market price can be taken as *numéraire*. Let us suppose it is i=1.This price is posited 1. The prices of other types of capital, being expressed in this numéraire, become price indexes. Let us call W the total value of wealth expressed in this price system:

$$W_t = \sum_{i=1}^{n} p_{it} K_{it} \text{ and } \frac{dW}{dt} = \sum_{i=1}^{n} p_{it} I_{it}$$

The condition of sustainability is dW/dt≥0. It can be used to measure weak sustainability where the range in the different types of capital is the most extensive that can be measured and where prices are the best possible approximations of shadow prices

Technological progress and population growth

The condition of sustainability can be defined in a slightly different way. Dividing both terms of the equation by the value of the first type if capital, one gets:

$$\left(dV/dt\right)\left(\frac{1}{p_1 K_1}\right) =$$
$$\left(1/K_1\right)\left(dK_1/dt\right) + \left(\frac{p_2 K_2}{p_1 K_1}\right)\left(1/K_2\right)\left(dK_2/dt\right) + \ldots + \left(\frac{p_n K_n}{p_1 K_1}\right)\left(1/K_n\right)\left(dK_n/dt\right)$$

The economy is sustainable if the sum of the growth in the volume of the different types of capital, weighted by their elasticity of substitution to the one type chosen as numéraire, is non-negative.

Now let us suppose that there is a Hicks-neutral technological progress. It can be interpreted as the rate of growth of "knowledge" taken as the numéraire. Its rate of growth is the growth rate (γ). in total factor productivity (TFP) With neutral technological progress the elasticity of output to knowledge is 1. Therefore the rate of growth of real wealth becomes simply the sum of TFP growth and the growth rates of the other types of capital:

$$\frac{1}{W}\frac{dW}{dt} = \gamma + \sum_{1=2}^{n} \frac{1}{K_i}\frac{dK_i}{dt}$$

One must measure the growth in the volume of the different types of capital, including TFP growth, and add up.

The formula is valid if population is constant. If population is growing at rate g, the sustainability criterion must be applied in calculating the growth of real wealth per capita with the caveat of constant population growth and independence of the distribution of wealth on population change:

$$\frac{1}{W}\frac{dW}{dt} - g = \gamma + \sum_{1=2}^{n} \frac{1}{K_i}\frac{dK_i}{dt}$$

Since the variation of total net real wealth or *genuine wealth* is net investment of society, the condition of sustainability is that does not destroy its wealth in mustering enough adjusted saving or genuine saving to match net investment. Therefore the sustainability condition becomes: the following: *the development path of an economy is sustainable if, at every date, adjusted social saving (or genuine saving) is non-negative.* If it gets negative, it means that society is destroying its wealth.

The definition of genuine saving is the following:

Genuine saving = economic gross saving of the nation – fixed productive capital depreciation + change in value of human capital + change in value of social capital – depletion of mineral and energy fossil resources – net reduction of forests – damages due to pollution in ≈ CO2

At that point the theoretical framework for development policies dedicated to the long-term goal of growth sustainability has been outlined. There are formidable obstacles to implement such a drastic change in policies from present practices that has lead to unsustainable credit dynamics in financial system, threats on sustainability of public debts, distorted income distribution and mounting ecological perils. On the perspective of measurement, the handling of public finances is the present priority, since they will be crucial in financing the investment necessary to the long-term accumulation of genuine real wealth. Then the measure of the types of capital that have been left aside in the national account systems is a precondition for conceiving adequate investment policies. It involves more than statistics. The choice of the long-term discounting factor, crucial for measuring most types of capital, raises very difficult ethical questions.

Sustainability of public finances

The sustainability of public debt raises complex measurement problems. Should gross or net debts be considered? If one thinks that net debt is relevant, what are the assets to be accepted on the other side of the balance sheet? On the liability side, there are contingent liabilities that do not show off in neither in the annual fiscal accounting nor in the national accounts. Should they be imputed in the public debt? How can they be valued? The problem has been dramatized while it has raised bitter controversies about the future sustainability of public pay-as-you-go pension systems. Assuming those problems are overcome, what is the proper criterion of sustainability? Is imposing an arbitrary limit (60% of GDP in the euro zone) a relevant and legitimate policy?

To address those questions one must first get familiar with public debt accounting (box 2).

Box 2. Public debt accounting

The fiscal yearly operating and income account is:

$H-T+iF_{-1}=\Delta D+\Delta M$

H is the amount of public expenditures, T receipts from taxes, D the stock of government bonds, ΔD the net annual flow and ΔM the monetization of the government deficit. There fore the left-hand side is the deficit and the right-hand side is its financing.

This accounting equation can be expressed as % of nominal GDP:

$h-\tau+(i-\pi-g)d_{-1}=\Delta d+\Delta m+(\pi+g)m_{-1}$

The primary deficit in % of GDP is not dependent on the capital market:

$b=h-\tau-\Delta m-(\pi+g)m_{-1}$

where $((\pi+g)m_{-1)}$ is the seignorage

One can define the ex post real interest rate adjusted to growth:

$\varrho=i-\pi-g$

The debt dynamic is described by the differential equation in discrete time:

$b+\varrho d_{-1}=\Delta d$

This equation is solved by iteration for a debt lasting n periods:

$$d_t = \mathrm{E}_t \delta_{t,n} d_{t+n} - \mathrm{E}_t \sum_{j=1}^{j=n} \delta_{t,j} b_{t+j}$$

The discount factor at n periods in the future is:

$$\delta_{t,n} = \prod_{s=1}^{s=n} (1 + \rho_{t+s})^{-1}$$

One may notice that *the discount rate for the public debt is the difference between the real interest rate paid on average on the debt outstanding (a function of the debt structure) and the rate of growth of the economy.* The discounted value of the debt in t is thus equal to the discounted expected value of the debt in t+n minus the discounted value of the primary deficits between t and t+n.

The condition of sustainability is obtained in letting n→∞.

The public debt is sustainable if its discounted value →0 whenever the debt horizon lingers to infinity. The condition is:

$$\lim n \to \infty \mathrm{E}_t \delta_{t+n} d_{t+n} = 0$$

It is the transversality condition, which means that the ratio debt/GDP must follow a stationary process for the public finances to be sustainable. It does not have to converge to any maximal predetermined value (60% or any other number). Its value depends on the profile of future primary surpluses:

$$d^* = -\lim_{n \to \infty} \mathrm{E}_t \sum_{j=1}^{j=n} \delta_{t,j} b_{t+j}$$

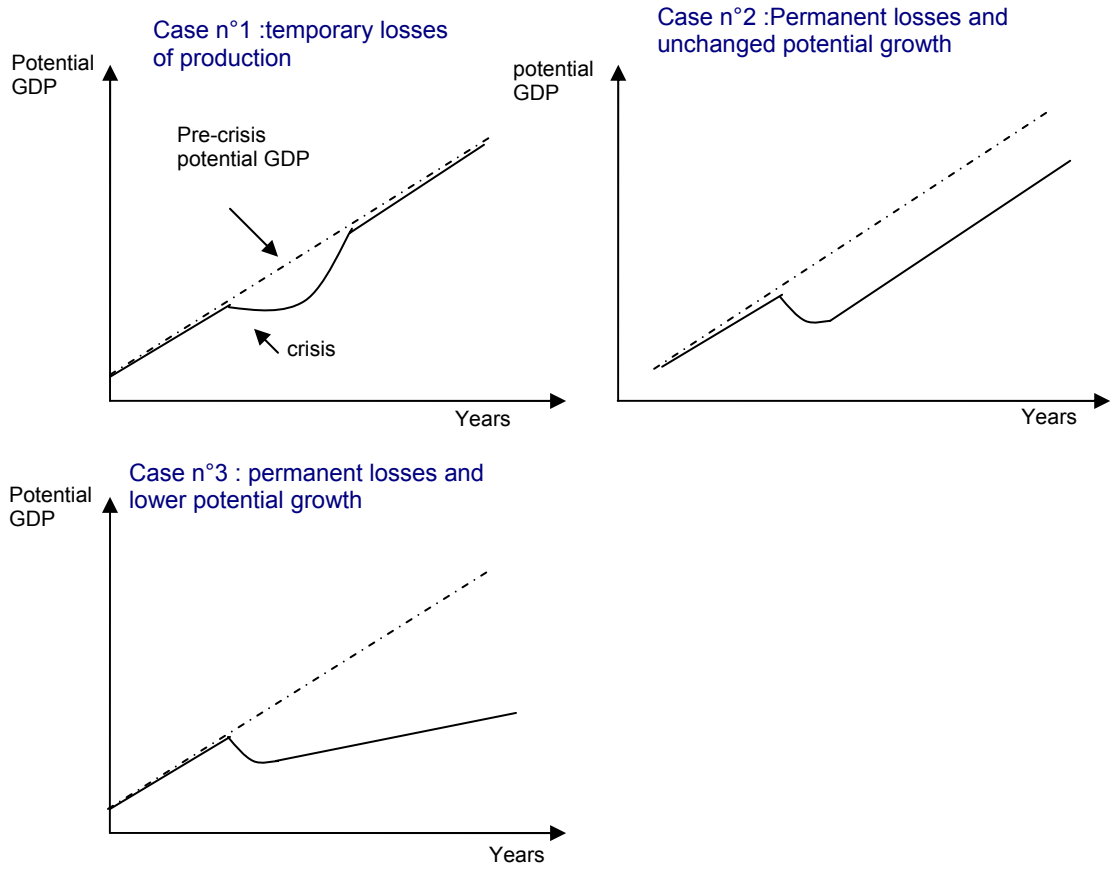
Box 2 shows that the present value of the gross sustainable debt in long-term equilibrium is the sum of the discounted expected future primary surpluses that finance it. The discount rate is all-important. The lower the discount factor, e.g. the higher the discount rate equal to the difference between the real interest rate paid on the public debt and the growth rate of the economy (r-g), the less far away future surpluses count in the value of the sustainable debt. In that case the sustainability condition implies a near-term consolidation of public finances. However a vicious circle can be engaged. After a financial crisis, for instance, a large amount of debt has been transferred from the private to the public sector. Too heavy and too fast a fiscal effort might lower the trend growth rate of the economy for a considerable period of time, thus lowering the discount factor even more so that the path of future debt gets unsustainable and a default becomes inevitable. The opposite arises if r-g is low. At the limit, under the golden rule (r=g) the discount rate is zero, meaning that all future primary surpluses are equivalent. The government disposes of an infinite period of time to straighten its finances. Of course, if r<g, the public debt is sustainable even if the government go on running primary deficits, because future tax revenues grow faster than the cost of servicing the debt.

Therefore the discount factor links the sustainability of the public debt to the larger condition of the sustainability of the growth regime defined above.

Figure 1 presents 3 scenarii that will have very different consequences for the future of public finances in OECD countries most affected by the financial crisis. In order to design a credible

medium-term program for future primary balances, governments must draw from past history of financial crises what will the most likely future growth path be. In turn, future growth will depend on the ability of government policies to influence growth in endogenous way.

Figure 1. Scenarii of future potential growth



To determine their medium-term consolidation plan, governments must have an objective d^*_{t+n} of their sustainable level of debt at the horizon (t+n) of their plan. This debt target must not be absurdly low. What is currently proposed by the EC Commission, to return to the arbitrary ceiling of 60% GDP for instance, would surely be a self-defeating target that would destroy the credibility of governments. Anyway, when they have fixed their targets, the condition of sustainability defined in box 1 applies in the following way:

$$d_t - \mathrm{E}_t \delta_{t+n} d^*_{t+n} = -\mathrm{E}_t \sum_{j=1}^{j=n} \delta_{t,j} b_{t+j}$$

The left-hand side is the desired variation of the present value of the public debt. The right-hand side is the discounted flow of primary surpluses that should be generated to finance it. As long as the equation is respected, sustainability is respected at the pre-set target.

The fiscal effort to be accomplished to satisfy the intertemporal budget constraint above is the difference between two ratios of fiscal revenues/GDP: the required minus the present fiscal pressure ($\tau^*-\tau$). It is determined by the following equation:

$$\tau^* - \tau = [\mathrm{E}_t \sum_{j=1}^{j=n} \delta_{t,j}]^{-1} [d_t - \mathrm{E}_t d^*_{t+n} + \mathrm{E}_t \sum_{j=1}^{j=n} \delta_{t,j} b_{t+j}]$$

It is such that the discounted value of the excess revenue due to the fiscal effort on (t,t+n) is equal to the difference between the discounted value of the desired variation of the debt and the present value of future primary balances that would have occurred whether past policy had been prolonged. Because neither the tax system nor the expenditure procurements are flexible at the will of government, the target level must not be arbitrary. The target level must be the result of an arbitrage between the requirement of sustainability and the political feasibility of a change in policy. The longer the time span of adjustment, therefore the lower the discount rate, the more leeway the government has to implement a credible program.

Whenever sustainability is a guide to policy from a deteriorated budget and a large increase in the public debt, it means that a fiscal effort must be engineered since $\tau^* > \tau$. In order to determine realistic future primary surpluses, a complete balance sheet of the government sector is useful. It is where future contingent liabilities and public sector assets must enter the picture (table 1).

Table 1. Government balance sheet

Items	Assets	Liabilitie
Fiscal assets and liabilities	Net present value of future tax revenues	Net present value of future primary expenditures
Financial assets and liabilities	Equity holdings in public sector companies Other financial assets	Gross public debt
Capital of the nation	Real assets	Net worth of the public sector
Public wealth	Total	Total

This presentation is a wealth accounting framework akin to a corporate balance sheet. The whole nation is the community of "shareholders" of the public sector. Therefore the net worth of the public sector is akin to an implicit equity of the people representing the nation. The net worth is a measure of the solvency of the nation, broader than the actual measure of the gross debt/GDP ratio and in line with the problematic of sustainability.

Whenever net worth is positive, the government can lower taxes, which increase the net wealth of household or wax investments, which increase public wealth and improve public services, without impairing the claims of bondholders. If net worth is negative, public finances are not sustainable. If an outright default is declared, bondholders will absorb financial losses. If consolidation policy is implemented to recover a positive net worth, taxpayers will suffer a loss in their wealth through higher tax burden or beneficiaries of public services will undergo a welfare loss through downgraded public services.

In future years government net worth in advanced countries will be negatively affected by the lingering impact of the financial crisis plus the permanent loss of output if scenario 2, or *a fortiori* 3 in figure 1, applies. Furthermore ageing will gradually create contingent liabilities through a rise in health and pension expenditures. The cost of ageing on public finances relies

heavily on long-term demographic and growth perspectives. They are linked to sustainable growth potential, whose estimate depends in turn on measuring genuine capital. If one admits that there are reasonably accurate procedures to measure fixed productive capital via perpetual inventory methodology, the most difficult task is measurement of intangible capital and of natural capital.

Sustainable growth: measuring intangible capital

Measuring intangibles has been a lingering problem of a long time, even more in business than in national accounting. In business the concept of capital is highly restrictive. The so-called intrinsic goodwill of the firm is a kind of dark pool, a source of profitability that is guessed and displayed in the financial markets when an M&A arises. Besides, national accountants have been reluctant to capitalize intangible expenditures. The accepted procedure is to treat expenditures on intangibles as intermediary expenses, not as investments that pertain to GDP.

However intangibles have been so boosted by the IT revolution that much more attention has been devoted in the last two decades. One can remember the Solow paradox in the late 80's: "you see the computer revolution everywhere except in the productivity data". The IT revolution developed the services industries where the measure of productivity depends on the ability of price indexes the quality change of the blossoming new products. The so-called hedonic prices tried to remedy this shortfall in some countries, but the conventions adopted to get them are debatable. Things began to change in mid-1990. However, there remained a suspicion that the accounting treatment of intangibles, as intermediary products, underestimated labour productivity..

A broad estimate of intangibles for 1999 in the US including software spending, R&D, human capital and the like arrived at a stunning result. Investment in intangible was around $1trillion, tantamount to the amount of investment in tangible capital at that time (*Corrado, Hulten and Sichel, 2005*).When they were highlighted, intangibles hidden in the national accounts had a large effect on GDP, rate of investment and labour productivity. The question raised by this point in time estimate were the following ones: do the biases in traduced by ignoring so large an amount of capital affect the levels only or the growth rates they impact? Whether the latter were true, how much growth is uncounted with omission of intangible capital? What is the contribution of intangible capital to overall growth? What is the relative importance of capital accumulation and TFP when intangibles are taken care of? These questions are methodologically important since TFP is a residual, the measure of our ignorance in understanding the growth process. Diminishing what is imputed to TFP is tantamount to an improved understanding of growth. Meanwhile, the system of national accounts has started to move forward, first in capitalizing software, then in accepting scientific R&D as capital expenditure. Yet it is only the tip of the iceberg. To understand the problems raised in valuing intangible capital, which motivate the reluctance of accountants, one must explain why intangibles are special in production and which categories of inputs define the domain under scrutiny.

Estimating intangibles.

Intangibles are pointed out to be non-verifiable and non-visible, which makes difficult or sometimes unfeasible the implementation of the perpetual inventory methodology. Some intangibles are non-rival or have non-appropriable returns. They are often in-house made, offering no arms-length market transactions as basis for quantifying. It is the case with the promotion of brands via advertising or other devices (brand equity) or corporate management rules. Furthermore separating price and quantity components is tricky, even finding unit of measure is not self-evident. When there are no observable market prices, input costs are used as a way to circumvent the lack of direct observation. Another means of approximation is the use of a generic output deflator, e.g. the non-farm business output price deflator, as long as specific price deflators are not available. It might be a better approximation if labour is not the single factor in producing the intangible. The lack of visibility stems from the absence of physical support about knowledge for instance. If it is accounted as capital, the link between investment expenditure and the stock of capital is hard to find out because depreciation rates are elusive. Nonetheless this characteristic does not impinge upon the way knowledge is used over time.

Non-rivalry raises the problem of measuring the marginal product of that type of capital. It might be zero in the direct production of the output. But it improves the efficiency of the process of production and of the quality of products. The non-appropriability of the return of some intellectual property means that their marginal product reflects only private benefits and costs. Nonetheless marginal principles should apply to their valuation. They should be valued according to the present value of the discounted future expected income they create. The reason is related to what has been said above about welfare theory. *Investment is defined as any use of a resource that that reduces current consumption in order to increase future consumption.* Consequently all types of capital must be valued symmetrically, be they R&D spending, employee training or spending in plant and equipment. It means that the side of consumption must prevail in unifying valuation principles, whatever the differences in production and the difficulties of practical implementation.

How does the treatment of intangible as intermediary product or as capital change national income? If spending in intangible capital is excluded from investment, it does not show in the national income identity that measures the rental flow on capital by the residual:

$$p_K K = p_C C + p_I I - p_L L$$

Let us call N the volume of expenditure in intangible capital in a given period and p_N its price, R the volume of intangible capital and p_R its user cost. The national income identity is:

$$p_K K + p_R R = p_C C + p_I I + p_N N - p_L L$$

The left-hand side of the identity is the non-labour payment accruing to both tangible and intangible capital. Global profit accruing to both tangible and intangible capital is thus higher.

To estimate the volume of intangible capital of a definite category in using the perpetual inventory methodology, one must calculate real investment by dividing the flow of nominal investment in a given period either by the average labour cost or by the non-farm business output deflator, depending on the nature of the category.

Human capital is embodied in people. In the case of human capital one can assume that the process of education earns the market rate of interest for the length of time spent in education. Since the investment in human capital can be approximated by the number of years of education (abstracting from the insuperable problem of accounting for differences in quality), human capital per worker is defined in steady state by: $H = he^{\rho A}$, where H is human capital

per worker, ϱ the appropriate rate of interest, the real value of yearly education expenditures per worker and A the number of years of educational attainment.

The stock of human capital is:

Total human capital = (human capital per worker)(number of workers), the number of workers being adjusted for mortality during working life. In competitive markets the marginal productivity of capital equals its shadow price, which is equal to the real wage. Therefore one gets: shadow price= (total real wage bill)/(stock of human capital)

For categories of intangibles that more alike tangible capital, one can use the perpetual inventory method. Real investment N is estimated in dividing nominal investment by the non-farm business output deflator. Applying the capital accumulation identity, the stock of capital R is determined by:

$$R(t) = N(t) + (1 - \delta_R)R(t-1)$$

How can δ and R(0) be chosen? If δ is relatively high, experts can choose a benchmark year where R(0)=0. Rates of depreciation are guesses from field experts.

It remains to calculate the user cost of capital according to the standard Hall and Jorgenson formula for each category (i):

$$p_{R,i} = [r + \delta_i - \pi_i]p_{N,i}$$

R is the competitive rate of return on capital, δ_i is the depreciation rate for asset I, π_i the expected capital gain or loss on asset i and $p_{N,i}$ is the investment price deflator.

Categorizing intangibles

The micro view of the firm and the macro view of development differ widely in the list of items they gather under the label of intangible investment. At the firm level, the concern is innovation, governance and social responsibility. At the larger macro level applying to development policy, the World Bank includes categories that are highly ideological and have been promoted with the Washington Consensus. Some of them are not measurable and are there just to claim that there only one best way: Western capitalism!

Of course human capital is common to both lists. Governance appears in both but has very different meanings. In corporate governance the ability to integrate the functions of the firm under a single goal and to control the managerial process is at stake. In governance viewed by the World Bank the yardstick is provided by US institutions. Institutional investments in other countries are ranked according to their distance with the US model. Such prejudice emphasizes formal institutions. The rule of law is attributed every virtue: social cohesion, political legitimacy and government effectiveness. This prejudice ignores completely informal networks of social cooperation like the Chinese “guanxi”.

Table 2. Categories of intangible investment and capital

Business intangible investment	**Developmental intangible investment**
Computerized info	**Human capital**
Innovative property: -R&D based on scientific knowledge	**Social capital** : -degree of trust in society

-Non-scientific commercial R&D	-ability to work for common purposes
Investment in organizational capabilities : -strategic planning -redesigning existing products -investment in brand names	**Governance:** -judicial system -property rights -legitimacy of governments
Investment in firm-specific human capabilities (management and professional)	**Other assets:** NFA + omissions in evaluating other forms of capital

Impact of business intangible capital on growth

In this section, one follows the work of Corrado, Hulten and Sichel on the US ("*intangible capital and economic growth"*), one of the most advanced researches so far. They compare GDP levels and growth rates in national accounts, in which most intangibles are treated as intermediary products, with the figures one might have reached had the accounts made the alternative hypothesis of intangibles as productive assets. Their methodology is described on box 3.

The growth accounting exercise delivers impressive results. Capitalizing intangibles increases the rate of growth of output per hour, both in the 1973-95 and 1995-2003 periods, so that the level is 20% higher than in national accounts at the end of the first period and 11% higher at the end of the second period.

The role of capital in labour productivity is much increased when intangibles are included. Conversely TFP growth declines in importance. The Solow paradox is resolved since the role of capital in the acceleration of productivity growth in the IT revolution is much larger with intangible capital.

Last but not least and contrary to well-anchored beliefs, firm-specific resources (organizational capabilities, firm-specific human capabilities and commercial innovative property) have had the most impact, while scientific R&D has had a much lower importance.

Box 3. Intangible capital and growth accounting

The notations have already been defined in the core of the paper. Two approaches of growth accounting are compared: one with intangibles as intermediate input and one with intangibles as capital.

Intangibles as intermediate input

There are three braches in the economy producing C, I and N with two factors of production L,K in all braches and N in C and I.

The production functions are:

$$N = F_N(L_N, K_N)$$
$$I = F_I(L_I, K_I, N_I)$$
$$C = F_C(L_C, K_C, N_C)$$

Assuming that the factors of production are paid at their marginal product, the income identities are:

$$p_N N = p_L L_N + p_K K_N$$
$$p_I I = p_L L_I + p_K K_I + p_N N_I$$
$$p_C C = p_L L_C + p_K K_C + p_N N_C$$

Under the assumption that all input markets clear, N is both an output and an input to produce other commodities. It disappears on the aggregate of GDP identity:

$$p_Y Y = p_C C + p_I I = p_L L + p_K K$$

In conventional national accounting, GDP growth rate (g_Y) is the sum of TFP growth rate (γ) and the weighted sums of the contributions of the factors of production growth rates. The weights are their shares in GDP assumed to be equal to the corresponding output elasticities.

$$g_Y = s_C g_C + s_I g_I = s_L g_L + s_K g_K + \gamma$$

Intangibles as capital

The output of intangibles appears in the production function of C,I,N as accumulative stock R.

The production functions are:

$$N = F_N(L_N, K_N, R_N)$$
$$I = F_I(L_I, K_I, R_I)$$
$$C = F_C(L_C, K_C, R_C)$$

The income identities in the three branches are:

$$p_N N = p_L L_N + p_K K_N + p_R R_N$$
$$p_I I = p_L L_I + p_K K_I + p_R R_I$$
$$p_C C = p_L L_C + p_K K_C + p_R R_C$$

The GDP identity:

$$p_Y Y = p_C C + p_I I + p_N N = p_L L + p_K K + p_R R$$

GDP is expanded to include the production of the newly-produced intangibles on the production side and the flow of services from the stock of intangibles on the income side. P_R is the user cost associated with the services of the intangible stock. This is a source of income absent from the intermediate input treatment. Subsequently GDP is more comprehensive and larger in magnitude. GDP being larger, the shares of the factors of production are recalculated.

$$g_Y = s'_C g_C + s'_I g_I + s'_N g_N = s'_L g_L + s'_K g_K + s'_R g_R + \gamma'$$

TFP growth and labour share are lower than with the former accounting rules. They are reduced by the coefficient $\lambda = \dfrac{p_C C + p_I I}{p_C C + p_I I + p_N N}$

The capital share is larger because it includes the share of income that accrues to intangible capital; hence the wage income in human capital is counted as capital income.

Sustainable growth: measuring natural capital

Natural capital is extraordinary diverse. The World Bank distinguishes subsoil assets forests and land resources. Subsoil assets are non-renewable fossil deposits: coal, oil, gas and minerals. Land is compounded of cropland, pastureland and protected areas. Forests encompass timber and non-timber resources. Other natural resources, like air and water, are impossible to be given monetary value. There are attempts to register them in energy-matter inventories: wild flora and fauna, wild fish in oceans, continental waters, etc…

The main problems to account for are the depletion on natural resources and the degradation of non-market natural wealth. As for non-market wealth, monetary evaluation in satellite accounts concerns the damages caused by economic activity to life diversity. Marketable natural resources are either non-renewable (energy and minerals) or renewable (forests and fish).

Prior to 1993, subsoil non-renewable resources were accounted in production at the time of extraction. On the contrary, newfound resources were not accounted at the time of discovery. In the 1993 system of national accounts, discoveries and takings on non-produced assets are registered in the account of other changes in volume.

All non-renewable resources generate rents, which are the basis for their evaluation. In the case of renewable resources, the duration of the stock is infinite and the intrinsic value of the resource that is taken is nil if the size of the taking is less than the natural growth. Under this condition, the total value of the sale of quantities that are seized from the stock are imputed to the production of forestry or fishing. In the opposite case, when depletion of the stock exceeds the natural growth, the exploitation of the resource is not sustainable.

Therefore net investment in forests is equal to: natural growth + (planting –amount used up)

A rent appears if: amount used up> natural growth.

The resource acquires an intrinsic scarcity value, e.g. a positive monetary rent. It should be treated in the same way as the rent of non-renewable resources (Vanoli, 1995). The stock of fish is excluded from this analysis because an excess of taking on the stock might be due to a temporary excess demand over the capacity of fishing. It is not the intrinsic rent but the costs that increase while the resource has been depleted.

All in all, the scarcity value of a renewable resource can be measured by the economic cost of the reconstitution of the asset at the level just prior the excess taking. This cost is the discounted value of the loss of income due to the limitation or the abstention of the taking while the resource is reconstituted.

In the framework adopted in this paper to model sustainable growth in connection with social welfare, natural capital must be measured because the environmental services they provide wane in quality and in quantity with economic activity. *Depletion in the stock of non-renewable resources, excess taking of renewable resources and pollution generate losses in the value of natural assets that reduce genuine saving*. Therefore they impact the variation of inter temporal social welfare.

Measuring the value of non-renewable assets

The value of subsoil assets must be estimated indirectly because there is no transaction of the total amount of oil or minerals buried in oilfields or in mines. One must calculate the economic resource rent, which is the net receipt of the exploitation of the underground resource for the total period of extraction. Then one must discount the flows of value at the present date.

The rent is the difference between the market value of the primary resource after extraction and the total of the costs incurred for prospection, development and extraction, including the normal return of the productive capital invested in the exploitation.

The rent is a pure scarcity value. Contrary to produced input, the rent of a non-produced input does not compensate any factor of production, since no factor has produced fossil resources. It is the value of a gift of nature created by human activity that uses it. In its 1997 report *("expanding the measure of wealth. Indicators of environmentally sustainable development"),* the World Bank defines the economic rent of a natural capital the following way: it is the inherent surplus value at the extraction or gathering of a primary resource. It is why it is called the intrinsic value of the resource whatever the owner, on condition that the owner (public or private), the prospector and the extractor are carefully distinguished. This "absolute" rent shall not be confused with differential rents due to the productivity differences in the costs of the different extraction processes and locations.

In national accounting the rent is measured as follows (Eurostat 2000, *Accounts for subsoil assets*):

Rent = extraction value at base price – intermediary input – wage compensation – net taxes on production – fixed capital depreciation – normal return on fixed capital (including intangible asset for prospection expenditures).

The taxes that must be imputed are taxes non-specific to the industry. Specific taxes are part of the rent. The main problem o f estimation stems from the net stock of fixed capital in the extractive industry and the choice of a "normal" rate of return for this stock. While total rent is calculated, one determines the share that accrues to the state, the share of the rent that is appropriated by the extracting firms is obtained by difference.

The value of the stock (V) is the present value of the discounted yearly rents (R) on the whole period of extraction:

$$V_t = \sum_{\tau=t}^{t+n} \frac{R_\tau}{(1+r)^{\tau-t+1}}$$

The crucial assumption is the discount rate. The World Bank has chosen a controversial social rate of return: $r=\delta+\eta g$ where δ is the pure rate of time preference, η the elasticity of the marginal utility of income and g the potential rate of growth of consumption per capita. Eurostat is even more open to criticism in picking up a rate closed to the average yield of public bonds in advanced countries. More will be said on the discount rate in the last section of the paper.

There is a simplistic and naïve way to neutralize the influence of the discount rate. This is the Hotelling rule, which assumes that the relative price of the scarce resource increases at a rate equal to the discount rate. In that case the value of the stock is just: $V=\varrho Q$ where Q is the quantity that has been extracted and ϱ the unit rent.

More generally the rent has the perverse effect of transferring value to non-producers. The capital gains of the rentiers are:

Capital gains = (rate of increase in real rent)(stock of resources)
Total capital gains = Σ capital gains over resource-owning countries = world capital losses of consumers

Rent has always been a curse for the development of capitalism. The increase in the real value of rents overtime raises the real price of the resource for users. Hence their real wealth declines involving a negative wealth effect on consumption. It is also a curse for the countries owning the primary resources. Most countries with a high share of resource rents, like Nigeria, Zambia or Venezuela, have experienced a long-run decline in real per capital income. Asian countries with very low exhaustible resources, like Korea, Thailand or India, have enjoyed high rates of capital accumulation and income growth.

There are three possible negative impacts of high levels of rents. The first is the Dutch disease, e.g. the overvaluation of the currency that thwarts profitability in industry, entails a low investment rates and laggard productivity of labour. The second is the inhibition for reform. The power of rentiers hampers the formation of a class of entrepreneurs and dissipates the rental value, instead of investing in education, health and infrastructure. The third is the volatility in the price of the resource that inhibits investment in exploration and technological improvement in extraction and transformation. Not all countries fall in this trap. The government of Norway has pursued a deliberate and pervasive policy of reinvesting the rent in order to substitute intangible capital (financial and knowledge-intensive industries) to natural capital (oilfields).

Agricultural land is measured in the same way as subsoil resources:

Value of crop land = present discounted value of land rents
Value of pastureland = opportunity cost of preserving land for grazing

Urban land is not treated the same way. It is conventionally computed as % of total productive capital.

Measuring damages to environmental capital

All kinds of damages should be measured and deduced to wealth accumulation in order to arrive at a satisfactory measure of genuine saving. However in the present state of blockade by powerful business interests and unwillingness of governments to acknowledge the seriousness of the risks, damages through natural resource depletion and air and water pollution are grossly underpriced.

The most unrecognized resource depletion arises with the destruction of the tropical rainy forests that are the most important carbon pits with the oceans. However, as a recent report of The Economist noticed ("*Seeing the wood*", September 25, 2010), "*the importance of plants' ability to store carbon in making the planet habitable is still not widely appreciated"*. About half the earth's original forest area has been cleared. The pace of deforestation has accelerated in the last 60 years. The rainy forests play a fundamental role in the sustainability of ecosystems. They capture and store carbon dioxide, all the more than the density of carbon in the atmosphere is higher. It is the carbon fertilization effect. They house more than half animal species and plants on earth. They are the source of a large array of staple foods and

medicinal plants. They regulate water run-offs, mitigating risks of flooding and droughts, since trees increase rainfalls and deforestation reduces it.

Forest degradation is still worsening in tropical regions (Amazonia, Indonesia, Congo) and in the boreal taiga. They are threatened by global warming and by the irresponsibility of governments. Global warming provokes the melting of the permafrost releases billions of tones of methane. It also entails calamities that are particularly dangerous for the integrity of forests: aridity, droughts, pests and fires. Those calamities entail deforestation that increases them in self-reinforcing feedbacks. Such vicious circles can bring the rainforests close to the so-called "tipping points" where they become ecologically unviable.

Furthermore governments do not resort to demographic policies, so that world population will expand from 6 to 9 billions in 40 years. With the present low level of agricultural productivity in Africa, the rising demand for bio fuels, palm oil and soybeans, the fast-waxing demand for food aggravated by the shift to meat in the diets of the middle class in emerging countries, the pressure for deforestation will be even more acute to release both crop and pasture lands.

To meet the challenge the UN has launched the much too modest Reduced Emissions from Deforestation and forest Degradation (REDD program). The idea is right: rich countries should pay poorer ones not to cut trees. They should do so because they need the rainforests to control their own climate. But the present amount of money in REDD is presently much too low ($4.5bns) to have a significant impact on the tens of millions of farms that settle close or in the forests.

To really stop the destruction of forests, let alone repairing the irreversible damage that has already been done, drastic changes must arise in national policies: much better forest management, land reform and upheld effort to improve productivity in agriculture and much tighter law enforcement. None of those shifts can occur if forests are not valued properly.

In present national accounting clearance of trees has value, standing trees have no values! This is crazy accounting that counts clearance positively and ignores the multiple costs from externalities that are the side effects of clearance. Clean air and non-acid rains are public goods that everyone wants and none is prepared to pay for. It is the role of governments to set a price on trees not to cut them off. *This value of non-use should be defined as the opportunity cost of cutting them down and selling them.* In principle the opportunity cost must embody all the environmental services that the rain forests provide, from water regulation to carbon sequestration and bio diversity protection.

A way to value at least partially this opportunity cost in order to stop deforestation is in pricing at least one of the main negative externalities, which is the release of carbon dioxide. Let us suppose that a farmer wants to clear a hectare of forest for pasture. One can calculate the amount of carbon emission that is released in the atmosphere by the destruction of this carbon pit. For a given price of carbon, one can determine the cast for the farmer, had it to pay for the marginal increase in emissions. If the cost is higher than the prospective gain of the projected exploitation, the tropical forest would be protected. However this device cannot work in every situation. In Africa deforestation often proceeds from survival by very poor people who needs deforestation to eat and to heat. Carbon credit can indirectly bring financial resources to finance micro development projects for those people in order to generate carbon credits for the local population.. However, to conceive and implement the micro projects, other instruments are needed (Christian de Perthuis, *"et pour quelques degrés de plus*", 2010).

Carbon credits are financial instruments to redistribute the costs of global damage from climate change. Indeed, all emissions contribute to global warming. But the impact of the

average increase of global temperature is latitude-dependent. Therefore there is a single social cost of carbon. Financial mechanisms must be agreed upon internationally to finance carbon reduction where it is most needed.

Because CO2 emission is a global externality that contributes to global warming whatever the location of emission, the marginal social cost of carbon is the weighted sum of future marginal damages generated by the emission of one more extra unit of CO2 equivalent at date t. The weighted coefficients depend on the discount rate and on the rate of natural absorption of carbon by carbon pits. The marginal cost of carbon is an increasing value of the amount of emissions. The marginal cost of emission reduction (marginal cost of abatement) is the cost incurred to diminish the volume of emission by one more unit of greenhouse gases. It is a decreasing function of the amount of emissions. The cost benefit analysis compares the marginal damage and the marginal cost of abatement for every level of abatement. At equilibrium: *marginal damage = marginal cost of abatement.* The price given by the equilibrium is the *social cost of carbon*. It should be the basis to price a carbon tax.

The problem is the practical quantification of the marginal damage function and of the cost of abatement function of the amount emissions because it is an undertaking rife with huge uncertainties. They limit the validity of cost benefit analysis in integrated evaluation models. To account for uncertainty about damages, the Stern review simulated numerous scenarios. Another method is the application of the precaution principle in defining an option value that makes allowance for the irreversibility of climate change. New information will be made available over time, which should be exploited to structure a sequential decision process. The calculation of the social cost of carbon emission, the construction of alternative scenarios and the decision process to allow for the option value of irreversibility, depend crucially on the discount rate.

Discounting the future under radical uncertainty

In traditional cost-benefit analysis the discount factor is the shadow price for discounting future costs and benefits. In the usual Ramsey optimal growth model, it is the amount of consumption an economic agent is willing to give up in the present to get one extra unit of consumption in the future. In a perfect foresight world the associated economic discount rate is the risk-free interest rate, equal to the rate of pure time preference plus the growth rate times the elasticity of substitution in marginal utilities. The latter parameter is equivalent to relative risk aversion under uncertainty. It is why the risk-free interest rate subtracts to the formula under uncertainty a term function of the variance of the density of probability function in the log of consumption.

This standard piece of theory fed the controversy on the Stern review (2007). Orthodox economists (Nordhaus, 2007) said that the discount rate used by Stern was much too low (he used the rate of pure time preference estimated at 0.1% for ethical reason). They said that indications drawn from the financial markets should be used to extract the risk-free interest rate. The stake of the controversy rests in the critical importance of the discount rate for Stern's conclusions on the need to act fast and invest massively to mitigate climate change.

In his Richard T. Ely lecture, Nicholas Stern ("*The Economics of Climate Change*", AER, Papers and Proceedings, 2008) reviewed the controversy in his turn and explained why referring to present market rates is quite wrong. The problem society faces is not a cost benefit analysis along a given path of the economy. It is the choice between very different

paths under radical uncertainty. Therefore it is necessary to go back to first principles of welfare economics.

A discount rate is the proportionate rate of fall of the value of the numeraire used in the policy evaluation. If aggregate consumption is the numeraire, as it is in standard welfare functions, the social discount rate is the rate of change of the social discount factor. If the social value of consumption at time t is: $u(c)e^{-\delta t}$, then the social discount factor is the marginal utility: $u'(c)e^{-\delta t}$ and the proportionate rate of fall is: $\eta(\frac{\dot{c}}{c}) + \delta$. In this formula, η is the elasticity of the social marginal utility of consumption with respect to consumption. δ is the rate of pure time preference. It has nothing to do with individual time preference. It is ethical and refers to the attitude of society facing its future. It should be taken to 0. The only reason why it might be taken slightly positive is the possibility of an ecological collapse that terminates life on earth as we know it.

The problematic of sustainable growth in the XXIst century is intertwined with climate change. The latter involves huge uncertainty. Therefore framing policy is not about arbitraging present and future consumption along a given path, it is about choosing between widely different consumption growth paths. Therefore the social discount rate is itself path-dependent, it varies over time, it is different for each uncertain sequence of outcomes and, with the highly imperfect financial markets the crisis has revealed, it differs according to the aggregate considered.

If δ should be taken close to 0, the value of η is itself highly ethical, since it depends upon the social distribution of income considered viable or desirable on a sustainable growth path. Indeed, η is about intertemporal distribution. η>1 implies a welfare-improving redistribution of income from the richest to the poorest. In highly unequal societies like the US, where income transfers induce strong disincentives, η is likely to be <1. In the context of uncertainty, η is interpreted as the parameter of relative risk aversion in an expected utility model of individual behavior. However, this interpretation is quite irrelevant for the radical uncertainty faced by societies as a whole. Ethics must be addressed directly.

Sustainable growth and climate change

Let us revert to the modeling of the social welfare function linked to the condition of sustainable growth paths displayed on box 1. This function assumes that environmental services are not perfectly substitutable with consumption. The long-term protection of environment should be pursued *per se* for the path of the economy to be sustainable. The diversity of discount rates, emphasized by Stern, is plainly illustrated. There is a standard discount rate defined as above. But there is also an ecological discount rate that reflects the relative price of the environment relative to consumption. Therefore another crucial and very uncertain parameter enters the picture, σ, that measures in highly aggregate model how substitutable consumption versus environmental goods are in producing social welfare. Furthermore, as forcefully claimed by Stern, in all practical terms σ is endogenous. It will change over time with investment in reduction and adaptation to climate change made along a given path. More importantly it will be quite different from one path to another.

In a recent very thoughtful and enlightening paper ("*ecological intuition versus economic reason"*), Olivier Gueant, Roger Guesnerie and Jean Michel Lasry illustrate the large diversity of social discount rates on growth paths that differ dramatically in the evolution of the relative price of environment.

They show that the future will be quite different if σ>1 or σ<1. They call the former hypothesis *moderate environmentalism* and the latter *radical environmentalism.* They show that the ecological discount rate is lower than the standard economic discount rate, the more than the growth rate is higher and the elasticity of substitution σ is lower.

If σ>1, consumption can be substituted to the services of the environment that are produced by natural capital, which is depleted over time. Because the contribution of the services of environment to GDP declines over time, the contribution of the environment to welfare diminishes and vanishes asymptotically. Even if the ecological discount rate is always inferior to the economic discount rate, the sustainable growth paths converge in the long run to the optimal growth rate in the Ramsey growth models: $\frac{r-\delta}{\eta}$ with the interest rate (r) measuring the intertemporal substitution in consumption.

If σ<1, the substitutability is low between consumption and environmental services. The picture changes entirely because the contribution of the services of environment in GDP increases over time with higher and higher relative price. *Environmental issues become paramount in the long run in sustainable growth paths.* The ecological discount rate is the one that matters more and it converges asymptotically towards the rate of pure time preference in the long run if natural capital is preserved. If there is a steady exhaustion of natural capital at the rate s, the discount rate can even turn negative asymptotically at the value: $\delta - \eta s$ with δ~0.

The teachings from this theoretical model vindicate entirely Stern's warning that the comparison between the economic dynamics implied by climate change involves policy evaluation quite aloof to standard welfare analysis. The paths of sustainable growth crucially depend on the substitutability between economic, human and other types of intangible capital on the one hand, natural capital on the other. The lower the substitutability between economic goods and environmental goods, the more restricted is the range of sustainable growth paths. The elasticity of substitution between natural capital and other types is therefore critical.

Since the elasticity is unknown a dilemma arises. Shall governments embark in a policy of massive investments in radical innovation at the expense of present and near-term consumption, in the hope that new renewable energy investments will make environmental and economic goods more substitutable in the longer term? Or shall they wait in the hope of getting more information on climate change developments and natural capital depletion at the risk of letting irreversible damage occurring?

Rationalizing the principle of precaution

To understand the radical uncertainty behind the illustrative theoretical model above, one must depict the compounded uncertainties in the chain of interactions between the chosen targets (limiting the rise in global temperature) and the policies worked out to meet the targets. A powerful paper by Martin Weitzman (*"on modeling and interpreting the economics of catastrophic climate change"*, RES, February 2009) helps understand what is at stake.

When policy is undertaken to reach a target, a complex chain of interrelations is presumed. The policy affects the flow of emissions of greenhouse gases (GHGs). Then one expects that the change in flows will impinge upon GHG stock concentrations via the carbon cycle. How much and how fast is unknown. The link between the stock of GHGs and temperature rise depends on climate sensitivity. There are several models run by climate experts that give

widely different orders of magnitude. Those global climate models must be used to make Monte Carlo simulations to estimate the probability distribution of outcomes. The links between global mean temperature changes and regional climate change are even more uncertain. Nonetheless they are crucial to guess the distribution of damages that should then be converted into economic damages that in turn impact the expected present value of social welfare. Applying the condition for sustainable growth that links the value of genuine saving to social welfare changes, one can finally assess the impact of a given policy. In repeating the exercise it is possible to compare policies and their associated growth paths.

It is easier said than done. The reason is that the complex chain of interactions encapsulates non-linear feedbacks that can deliver catastrophic outcome. It means that standard cost-benefit analysis is plagued with probability density functions in the reduced-form model of aggregate expected utility that have tails much fattened by structural uncertainties.

Climate sensitivity is one such interaction. For instance the target of limiting GHG concentration at 550ppm ~CO2 gives 24% probability of temperature increase over 4°C and 7% probability over 5% with an average global climate model. Some models arrive at much higher tail probabilities. Indeed, climate sensitivity may exhibit tipping points beyond which positive feedbacks produce uncontrollable runaway outcomes. If nothing is done, business as usual might entail 5% probability of 10°C increase in temperature. Such an outcome will destroy much life on earth. There will be mass species extinction and ecosystem disintegration. All ice fields will thaw and the level of the sea will rise 10 meters or more, flooding the most populous regions of the world. The pattern of rainfalls will be completely disrupted and the drastic changes in precipitations will provoke regional desertification on a grand scale. The consequence will be mass migrations and wars whose consequence will be a likely drastic decline in world population.

If, as most reasonable people are now aware of, business as usual is not an option for sustainable growth, the question is about designing policies and the schedule to implement them. Stern has calculated in his simulations that, starting today at 430ppm and setting the goal of stabilizing GHG concentration ≤550ppm will cost 1% world GDP per year with good policies and timely decisions. Delaying action until one has more information on the function relating temperature increase to GHG concentration might cost 3 to 4 times as much to achieve the same target.

One can understand now Weitzman's rationale. Under present knowledge, the aggregate discounted welfare function has a fat-tail probability distribution of catastrophic climate change. The loss of welfare can be bounded only by a very high number, which is nothing less that the statistical value of human civilization. As argued above, we are entirely and uniquely in the realm of ethics.

Weitzman models the climate-sensitivity multiplier as an unknown scale factor (s). The probability density function of future consumption is conditional on s. Weitzman shows that, when the unknown s is estimated via an inductive reasoning by climate experts observing past climate outcomes, the probability distribution of future consumption posterior to the Bayesian knowledge on s is a Student-t function. It converges asymptotically to a fat-tail power law. In this stochastic universe, the expected discounted factor of future costs and benefits tends to infinity and the social discount rate tends to zero.

This way Weitzman arrives at a "*dismal theorem"*. The probability of disaster declines polynomially in the scale of s, while the marginal utility impact of an ecological disaster increases exponentially in the scale of s. The theorem is valid for any utility function with a positive risk aversion.

The very nature of the systemic risk involved by climate change stands out. In financial systemic crisis not all asset classes are struck by losses. High-powered money stands out as pure liquidity against all other assets and polarizes the behavior of people in search of a refuge. In systemic climate crisis there is a possibility that overall damages strike all asset classes. All the components of real wealth might suffer losses worldwide.

Therefore the dismal theorem validates a generalized precautionary principle for situations of potentially unlimited downside risk exposures. Because knowledge about the tail of the distribution cannot be drawn from past observations, individuals are projected in the domain of subjective uncertainty, where no market mechanism can induce any rational conduct. Only collective action based on strong ethic that cares on the welfare of future generations may produce proper policies. Because the structural uncertainty involved is hidden by high inertia, catastrophic consequences of climate change may unfold over a time scale of centuries, while the policies to hamper them should rely on implementation beginning now. The collective decisions are critically sensitive to the discount rate that is postulated. The underlying choice of the social discount rate and the accompanying structural policies to increase the substitutability between asset classes, in order to sustain a viable growth path, amount to a generalized dynamic asset allocation strategy, legitimized by the whole society in every part of the world. Representative elective democracy is not sufficient to organize the social debate necessary to legitimize the long-run view that will shape the right policies. Ethic must take over in the choice and the reproduction of elites. The criteria of social merit and recognition must change entirely. A deeper, more socially responsible, participative democracy must emerge.

Bibliography

Aghion P., Hemous D. and Veugelers R. (2009), "No green growth without innovation", *Bruegel Policy Brief*, n°7, November

Arrow K. (1995), "Intergenerational Equity and the Rate of Discount in Long-term Social Investment", Stanford University Department of economics, Working paper n°97-005

Arrow K, Dasgupta P., Goulder L., Daily G., Ehrlich P., Heal G., Levin S., K-G Mäler, Schneider S., Starret D. and Walker B. (2004), "Are we consuming too much?", *Journal of Economic Perspectives*, vol. 18, n°4, Summer, p.147-172

Arrow K, Dasgupta P., Goulder L;, Mumford K. and Oleson K. (2007), "China, the US and sustainability: perspectives based on comprehensive wealth", Stanford Center for International Development, January

Aukrust O. (1966), "An axiomatic approach to national accounting. An outline", *Review of Income and Wealth*, September, p.179-190

Barnett G.E. (1936), *two tracts by Gregory King*, John Hopkins

Becker G. (1964), *Human capital. A theoretical and Empirical Analysis with Special reference to Education*, Columbia University Press

Beckerman W. and H. Cameron (2007), Ethics of the discount rate in the Stern Review on the economics of climate change", *World Economics*, vol.8, n°1, p.187-210

Bénard J. (1972), *Comptabilité nationale et modèles de politique économique*, Thémis

Bosetti V., Carraro C., Duval R., Sgobbi A. and Tavoni M. (2009), "The role of R&D and technological diffusion in climate change mitigation: new perspectives using the Witch model", *OECD Working Paper*, n°664, February

Bowman M.J. (1968), « Principles in the valuation of human capital », *Review of Income and Wealth*, September, p.217-246

Carson C ; (1975), « the history of the US national income and product accounts: the development of an analytical tool", *Review of Income and Wealth*, June, p.153-181

Clark C. (1940), *The Conditions of Economic Progress*, Mac Millan

Corrado A., Hulten C. and Sichel D. (2005), "measuring Capital and technology: an expanded framework", in measuring capital in "The New Economy", C.Corrado, J. Haltiwanger and D. Sichel eds., *Studies in Income and Wealth*, vol.65, University Chicago Press

Corrado A., Hulten C. and Sichel D. (2006), "Intangible capital and Economic growth", *NBER Working Paper*, n°11948, January

De Perthuis C. (2010), *Et pour quelques degrés de plus*, Pearson, 2ième ed.

Desaigues B. et Point P. (1993), *Economie du patrimoine naturel. La valorisation des bénéfices de protection de l'environnement,* Economica

Diamond J. (2005), *Collapse*, Penguin Books

El Serafy S. (1989) "The Proper Calculation of Income from Depletable Natural Resources", in Y. Ahmad, S. El Serafy and E. Lutz eds., *Environmental Accounting for Sustainable Development,* World Bank

Gilbert M. et Kravis I. (1954), *Étude comparative des produits nationaux et du pouvoir d'achat des monnaies,* OECE

Gilbert M. and Associates, *Comparative National Products and Price Levels*, OEEC

Goldsmith R. (1962), *The National Wealth of the US in the Postwar Period,* Princeton University Press

Gollier C. (2007), "la finance durable du rapport Stern", *Revue d'Economie Politique*, vol.117, n°4, Juillet-Août

Gueant O., Guesnerie R. and Lasry J-M. (2010), "Ecological Intuition versus Economic Reason", communication au colloque international d'Aix en Provence sur le financement du long terme, 27-28 mai

Guesnerie R. (2004), « Calcul Économique et Développement Durable », *Revue Economique*, vol.55, n°3, p.363-82

Hamilton K. and Clemens M. (1999), "Genuine Savings rates in Developing Countries", *World Bank Economic Review*, vol.13, n°2, p.333-356

Harrison A. (1989), « Introducing natural Capital into the SNA », in Y. Ahmad, S. El Serafy and E. Lutz eds., *Environmental Accounting for Sustainable Development*, World Bank

Hicks J. (1940), « the Valuation of Social Income », *Economica*, May

Hicks J. (1942), *The Social Framework*, Oxford University Press

Hicks J. (1961), "The measurement of capital in relations with the measurement of other aggregates", in F.A.Lutz and D.C.Hague eds, *The Theory of Capital*, Mac Millan

Kendrick (1976), *The Formation and Stocks of Total Capital*, Columbia University Press

Keynes J.M. (1940), *How to Pay for the War*, Mac Millan

Kravis I., Heston A. and Summers R. (1982), *World Product and Income: International Comparisons of Real Gross Products,* John Hopkins

Kuznets S. (1973), *Population, Capital and Growth: Selected Essays*, Norton

Landes D. (1998), *The Wealth and Poverty of Nations*, Little, Brown and Company.

Leontiev W. (1941), *The Structure of the American Economy 1919-1929: an empirical application of equilibrium analysis,* Harvard University Press

Lev B. (2001), *Intangibles: Management, Measurement and Reporting*, Brookings Institution

Lutz E. (1993), *Towards Imported Accounting for the Environment,* World Bank

Maddison A. (2003), *The World Economy: Historical Statistics*, Development Center Studies, OECD

Maddison A. (2007), *Contours of the World Economy 1-2030 AD*, Oxford University Press, chap.6, macro measurement

Mairesse J. (1972), *L'évaluation du Capital Fixe productif. Méthodes et Résultats,* Collections de l'INSEE, série C, n° 18, novembre

Mairesse J. and Kosoglu Y. (2005), "issues in measuring knowledge: the contribution of R&D and ICT to growth", communication to the Advancing Knowledge and Knowledge Economies, Conference at the national Academies, Washington DC, 10-11 January

Meade J. and Stone R. (1941), "the construction of tables of national income, expenditure, savings and investment", *Economic Journal*, May-September

Nordhaus W. and Tobin J. (1973), "Is growth obsolete?", in M. Moss ed.; *The measurement of economic and social performance,* Columbia University Press

Nordhaus W. (2007), "A Review of the Stern Review on the Economics of Climate Change",, *Journal of Economic Literatur*e, vol.45, n°3, p.686-702

Parson E. (2007), "The big one: a review of Richard Posner's catastrophe: risk and response, *Journal of Economic Literature*, vol XLV, March, p.147-164

Pearce D.W. and Atkinson G. (1993), "capital theory and the measurement of Sustainable development: an Indicator of Weak Sustainability", *Ecological Economics*, n°8, P.103-108

Pigou A.C. (1932), *The Economics of Welfare*, Mac Millan, 4th edition

Posner R. (2004), *Catastrophe: Risk and Response*, Oxford University Press

Ramsey F.P. (1928), "A mathematical theory of saving", *Economic Journal,* vol.38, n°152, p.543-559

Sametz A.W. (1968), "Production of Goods and Services. The Measurement of Economic Growth", in E.B. Sheldon and W. Moore eds., *Indicators of social change. Concepts and Measurement,* Russel Sage Foundation, p.77-96

Samuelson P. (1950), "Evaluation of real national Income", *Oxford Economic Papers,* n°2, p.1-29

Schultz T.W. (1961), "Investment in human capital", *American Economic Review*, March, p.1-17

Sen A. (1976), "Real National Income", *Review of Economic Studies*, February

Sen A. (1979), "The welfare basis of Income Comparisons: a survey", *Journal of economic Literature,* March, p.1-45

Siglitz J., Sen A. and Fitoussi J.P. (2009), *Rapport de la Commission sur la Mesure de la Performance Economique et du Progrès Social*

Stern N. (2007), *The Economics of Climate Change. The Stern Review*, Cambridge University Press

Stern N. (2008), "The Economics of Climate Change", Richard T. Ely Lecture, *American Economic Review Papers and Proceedings*, vol.98, n°2, P.1-37

Stone R. (1947), "Definition and measurement of the national income and related totals" in *Measurement of national Income and the Construction of Social Accounts*, UN.

Stone R. (1956)*, Quantity and price Indexes in National Accounts*, OECE

Studensky P. (1958), *The Income of Nations*, New York University Press

Uno K and Bartelemus P. eds (1998), *Environmental Accounting in Theory and Practice*, Kluwer

Vanoli A. (1995), "Reflections on Environmental Accounting Issues", *Review of Income and Wealth,* March, p.57-71

Vanoli A. (2002), *Une Histoire de la Comptabilité Nationale*, Repères, la Découverte

Weitzman M. (2009), « On modeling and interpreting the economics of catastrophic climate change », *Review of Economics and Statistics*, vol XCI, n°1, February

World Bank (1995), *Monitoring Environmental Progress*

World Bank (2006), *Where is the Wealth of Nations? Measuring Capital for the 21st Century*