Stocks and Flows of Knowledge and their Relation to the Sustainability of the Information Society

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Abstract: The TERRA2000 project uses data, models and scenarios to examine the economic, social, environmental and cultural sustainability of the global networked knowledge society. The measurement of knowledge is key to this enterprise. However, to speak of the 'Knowledge Society' in this context is at once too complex and too simple: it is too complex because available data can, at best, be used to measure information or produce indirect indicators of knowledge and because the knowledge thus measured resists aggregation. It is too simple because the global networked knowledge society is at least as strongly influenced by the distribution of knowledge and by beliefs as it is by knowledge in the epistemic sense. The increasing knowledge intensity of economic and societal interactions, combined with new forces of globalisation and networked interaction, have produced a fundamental tendency towards fragmentation and inequality and towards concentration of market power and the emergence of possibly inefficient conventions. The economic and academic incentives influencing the creation, dissemination and use of knowledge may threaten its evolution, driven by the forces of variation (innovation), selection (scholarship and market-testing) and heredity (teaching and codification).

The lack of suitable data forced several innovations. In some cases, 'paradigmatic' and/or game theoretic models were calibrated to available figures to directly capture at least the qualitative dynamics of e.g. networking, knowledge creation and dissemination. In other cases, dominant relations models were used to make optimal use of available indicators. New measures relating to values, exergy, motivation, access and labour skills etc. were created, along with novel indicators of dematerialisation, immaterialisation and equity. This paper discusses the analytic challenges and the general strategy of using different types of models and scenario analysis in combination with empirical data to extend the reach and of evidence relating to the Information Society.

1. Introduction

This paper addresses some conceptual and practical issues arising in trying to understand the sustainability implications of the “Information Society.” From the standpoint of knowledge, it raises several broad observations.

- Knowledge is intangible
- Knowledge arises from information and thus from the interpretation of data
- Knowledge has some, but not all, of the characteristics we associate with capital
- Knowledge can be instantiated in various ways
- Knowledge derives value from its use in human activity
- Knowledge cannot easily be aggregated
- Knowledge evolves
- Knowledge is created and exploited through networks
- The distribution of knowledge is as important as its ‘quantity’

These are discussed in more detail in Section 2. Section 3 introduces the TERRA project, which examines the sustainability of the information society. In view of the complexity of the phenomena and the conceptual and measurement difficulties surrounding the principal issues (including knowledge), the project developed a range of data resources (some of which provide indirect indicators of knowledge stocks, distributions and flows), different types of models, scenarios and an analytic ‘backbone for developing policy-relevant insights. The final section brings these aspects together with the fundamental questions in two particular directions: the relation of R&D and productivity and the case for intellectual property rights (IPR).

2. The Broad Observations

Knowledge is intangible – it is often measured indirectly, and these measurements must be transposed into suitable indicators rather than being used as direct, valid and verifiable measures of an objective and aggregable quantity. Moreover, the ‘input measures’ of knowledge creation do not map smoothly, deterministically or monotonically into ‘output’ measures, in particular, knowledge as an economic input or output must be measured in efficiency units.

Data, suitably interpreted, give rise to information and thence to knowledge – but even these are difficult to define in meaningful ways. Concrete definitions and measurements must be tuned to specific questions and to the disciplinary perspectives of those making or using the measurements. For instance, measurements of data flow in bytes/second cannot distinguish signal from noise; measurements of information in entropic terms do not match measurements in terms of the ‘value of information’ (its potential influence on decisions and their consequences). In addition, because data and even information can be easily stored and reproduced, separating them from their instantiations may be difficult. The value or incremental effect of new data, information or knowledge depends on their current states, which themselves may be almost impossible to measure. Finally, from an epistemic perspective knowledge in the strict sense may not be wholly relevant; belief may be much more significant for understanding socioeconomic phenomena; the relations of knowledge, truth and belief may be different than we assume; and the differences between that which everybody knows and that which is common knowledge (and all the gradations in between) may be most important of all.

Knowledge has some, but not all, of the characteristics we associate with *capital*. That is, it offers benefits in future in exchange for investments today (it transfers value over time); it is not necessarily consumed when used to produce value; it is a carrier of value; it can (to some extent) be transferred; it may be subject to depreciation; and (again with limitations) it can be made the subject of property rights. However, these analogies are limited in significant ways. The problems of aggregation of physical capital, for instance, pale into insignificance in comparison with the difficulty of aggregating knowledge. For instance, knowledge that is used to inform action depends for its magnitude (or value) on its coherence and relevance. As studies of consumer behaviour show, adding more knowledge may make practical choice problems impossible to solve. When individuals draw inferences from each others' behaviour, increasing the knowledge of one party may well make everyone worse off. For theoretical reasons, knowledge embodied in formal systems gives rise to inconsistency or essential incompleteness, so adding knowledge may make choice problems impossible to solve. More directly, if individuals are motivated to acquire and apply knowledge by external rewards, extending knowledge to others may destroy its value: a person with 'insider' knowledge of a business situation controls a valuable asset – once it becomes commonly known that value disappears. Other parts of the capital analogy are similarly flawed: by contrast with physical capital, human capital (one form of tacit knowledge) may well depreciate to the extent that it is not used; new knowledge may destroy old knowledge, or may be destroyed by exposure to it. Finally, IPR are significantly difficult to define and use.

Knowledge can be instantiated in various ways – we typically distinguish at least three forms of knowledge. Codified knowledge is knowledge converted to information – it has a physical instantiation separate from the knower: a text, a line of code, a patent, etc. Tacit knowledge is embedded in something else from which it cannot easily be separated – the two most common versions being technology embedded in physical objects and the skills and know-how that comprise human capital. Finally, systemic knowledge is neither separable from human beings nor tied to any single one, but depends on their societal or other relationships. In some sense, it represents an emergent phenomenon like the coherent problem-solving behaviour of termites.

Knowledge derives its particular value from its use in human activity – this suggests that the appropriate way to measure the value of knowledge is to adopt a real options approach that takes account of the impact of a body of knowledge on future decisions and their anticipated outcomes. In many cases, those decisions will be informed by subsequent knowledge or information: thus a University degree does not contain the knowledge needed to perform in the workplace, but may provide an essential precursor to life-long learning. In some cases, it is possible to use market-based measures to aid in this evaluation (.g. the differential income attached to a University degree) but this depends on the efficiency of these markets and on the analyst's ability (or willingness) to separate the knowledge part from the certification and signalling components. But this perspective gives a clear indication as to why society tends to place a higher value on demonstrated capacity to learn than it does on demonstrated training in specific skills. This differential should increase as the pace of change increases, indicating that different kinds of knowledge, not more knowledge, are needed. The challenge for the analyst is to find reasonable ways to measure 'kind.'

Knowledge cannot easily be aggregated. Codified knowledge cannot be measured by counting its physical manifestations – a book that can be copied may be the same as many copies of that book. And yet, these manifestations are not irrelevant: the more copies there are, the more people to whom they are accessible and the more people are familiar with the material and able to help others turn the information back into knowledge, the greater is the (potential) knowledge represented by the book. Tacit knowledge is even harder to aggregate. Consider the aggregation of knowledge across individuals: as tests of 'hand-on' performance against examination performance show, some tasks (e.g. map-reading) can be performed well by a group if (and sometimes only if) only one member of the group has relevant knowledge. Other tasks depend on the 'weakest-link' (the minimum knowledge in the group), the average, the 'strongest-link', etc. Nor is the aggregation of knowledge across types of knowledge any easier. Some types of knowledge are essentially substitutes, while others are complementary (the whole greater than the sum of its parts). Some types of knowledge are (or are believed to be) essentially convergent – such as scientific knowledge, where intellectual competition should help good knowledge drive out bad. In this case the value of a stock of knowledge depends on the speed and certainty with which it reaches a 'good understanding.' Other types of knowledge, such as artistic knowledge, may be divergent, and derive their value from either their coherence or their diversity.

Knowledge evolves. At the end of The Selfish Gene, Richard Dawkins observes that the evolutionary principle applies as much to ideas as to organisms. The study of such 'mimetic' evolution, driven by more-or-less successful attempts to make copies of ideas or of rules for generating ideas (see e.g. Blackmore's The Meme Machine) highlights the role of knowledge in generating new knowledge. Just as we would measure a fertile seed differently than one equipped with a 'terminator gene,' so we should measure knowledge in terms of its productive capacity. Evolution in general arises from three forces: variation (innovation, error), selection (scholarship, market-testing) and heredity (teaching, publication). Useful measures (or representations) of knowledge should take all these into account. Further insight can be derived from the specific elements and from modelling the incentives built into the system – in other words, where direct measures of knowledge fail, we can usefully measure the system and behaviour that produces them. Two examples are provided by the structure of IPR and incentives to originality. Patent protection is granted to ideas that are original, useful and non-obvious. This places a premium on, among other things, originality. The grant of a patent 'protects' a neighbourhood of the original innovation. This can either encourage or discourage the generation of new knowledge, depending on the expected costs and benefits of developing alternatives, the extent of complementarities and 'lock-in' effects and the structure of granted rights. As is well-known, the depth, breadth and duration of such protections can have profound effects on innovation: patents that are too basic or too broad can effectively foreclose markets, while patents that are too narrow are not worth obtaining and thus restrict the flow of knowledge, or lend themselves to sterile 'mere novelty' (as in the recent practice of using the genetic algorithm to find the closest non-infringing innovation. In addition, while IPR protections are directly concerned with knowledge, their primary motivations often lie elsewhere. Where the primary motivation is economic, patents may be sought in order to deter entry (predatory patenting) or structured in a way that limits the threat of competition or takeover (patent thickets or clusters). Other rights derive from the career incentives of knowledge creators. An emphasis on originality reduces incentives to replicate or verify others' work, thus weakening the 'selection' part of knowledge evolution, or encouraging trivial modifications of existing knowledge. On the other hand, strong editorial preferences may encourage 'clustering' of ideas around the viewpoint of specific journal and the reinforcement of orthodoxy. These and other aspects have been considered carefully in the recent debate over 'open-access' models of scientific publishing.

Knowledge is created and exploited through networks. Knowledge is created by networks of interacting individuals and institutions. The structure of these networks determines the pace and direction of knowledge creation and transfer. Conversely, knowledge itself is embedded in a semantic web of interrelated concepts, and the quantity and dynamics of knowledge have their most important 'footprint' in this structure. Knowledge measurement should thus take account of the underlying *network structure*. For instance, it is known that networks oriented knowledge creation have different structures than networks orientated towards the exchange or exploitation of knowledge. While any such network will produce variation, selection and transmission of knowledge, the objectives of its members and the structure of their relationships will determine the strength of those effects. To frame these impacts, we can distinguish different forms of network description. For simplicity, we here discuss the human and institutional network only.

The simplest is based on *group membership* – how inclusive or exclusive is the group, and what overlaps are there between different groups? For instance, possession of compatible or complementary knowledge creates a strong *network externality* like the interoperability advantages associated with ICTs. The consequences may be a 'clumping' of individuals and a trade-off that favour interoperability over diversity and innovation. It may also display a tipping tendency towards standardisation, orthodoxy and monopoly. On the other hand, it also supports fairly clear standards of quality, since comparison of unrelated knowledge are less frequent. Another positive knowledge network externality is the availability of others whose interests and knowledge are sufficiently similar to allow them to provide critical discussion and cooperative testing of new knowledge. On the other hand, some externalities are negative: for instance, wide dissemination of knowledge reduces its proprietary value and a great diversity of knowledge around a specific problem may make it more difficult to select or implement an evidence-based solution. A further set of externalities concern *trust* – trust in knowledge and trust in the work of other scholars. This can clearly be seen in the very different structures of knowledge in fields where the probity of the human source is all-important (e.g. law, where 'authority' is a crucial quality indicator) and those where the soundness of the idea is paramount (e.g. mathematics).

Next comes the binary *network structure* – what linkages connect nodes in the network (be they individuals or institutions), how strong are they and are they one-way or reciprocal? Note that some links are transactional – co-publication, patent licensing, conference attendance, etc. – while others derive from the semantic web: scholars working on a given idea are brought into closer proximity as a result. This incidentally shows that powerful nodes in one network can affect the geometry of another: people working on similar lines tend to collaborate or even collocate, while people working with a powerful scholar tend to produce a body of knowledge clustered around that 'hub's' interests. The network structure can be analysed in terms of path lengths, distribution of 'power,' 'clustering', etc. For instance, in a 'small worlds' network an individuals' neighbours tend to be linked to each other – alternatively, members of a cluster have more or stronger links to each other than to outsiders. Clustered networks may be better for development of new knowledge than for its transmission, and may more easily fall into scholasticism.

Beyond network structures lie network influences on *behaviour*. Among the most important behaviours are those concerned with sharing of ideas and team working. There is some evidence that different types of knowledge creation do best in different types of networks (comparing, for instance: star networks with strong 'expert' hubs capable of coordinating decentralised activities; fully-connected networks in which all are equal and equally close to each other's work (or in which all possess the same knowledge); and ring networks in which each interacts with only a small set of neighbours, but none is more powerful than another.

Recent advances in the modelling of networks have obtained some interesting results – for instance, in models of either network formation or behaviour choice within networks there is often a tension between stability and efficiency.

The distribution of knowledge is as important as its 'quantity.' Recent econometric analysis (in TERRA and elsewhere) has examined the adequacy of aggregate measures of knowledge in models of productivity, or production. These studies have increasingly shown that the distribution of knowledge plays a crucial role. For instance, the inclusion of aggregated human capital measures (e.g. average years of schooling) in macro production functions usually produces statistically significant results, but they either have an inverted U-shape (human capital increases GDP/capita in underdeveloped countries, but decreases it in developed ones, due to over qualification, the cost of extended schooling for large fractions of the population and immiserising competition among the qualified[1]. However, when these aggregates are supplemented or replaced by measures of knowledge *inequality*, the results are stronger and give the anticipated results that more inequality is bad for growth. These results have both static and dynamic implications. They suggest that increasing education – and general education at that – is more likely to produce sustained growth than focussed investment in specific technologies or training. They also indicate that the negative externalities and tipping tendencies associated with knowledge externalities themselves lead to increasing inequality. This first manifests itself in income inequality - the increasing gap between the pay of high- and low-skilled workers, between countries with high levels of knowledge capital and those without, and recently even to gaps within skill levels as a result of competition for a limited number of 'top-flight' knowledge intensive jobs. Over time, to the extent that motivation, access and skills required to obtain and exploit education are affected by wealth, the income inequality can harden into further knowledge inequality and ultimately to societal inequality.

3. The TERRA perspective

3.1. The Global Networked Knowledge Society

The TERRA2000 project is concerned with the sustainability of the Information Society. More directly, its object of study is the Global Networked Knowledge Society (GNKS). This slightly precious term seemed to us to capture the most important aspects, at least as concerned the factors usually omitted from studies in this area.

- *Global*: through Internet, global business, media and increasing travel, no society remains totally isolated and many central problems and potential solutions are global;
- *Networked*: through telecommunications and ICT, geographic distance no longer has the same effect on interaction and team-work. Some businesses, governments, consumers and citizens around the globe have direct network access – but as late as 2001, according to ITU estimates, less than 20% of world population had a telephone line and only about 8% had Internet access; these are equal across regions or socio-economic groups.
- *Knowledge society* (more than "Information Society" in the narrowest sense): information access can be relatively easy and inexpensive but the knowledge required to use it effectively requires insight, education and tools that are difficult and expensive to acquire and share. The word 'society' is included as a reminder that the knowledge transformation transcends the economy.

Arguably, the "newest" aspects of the New Economy are globalisation and knowledge in a mutually reinforcing relationship with networking and information as the basis for economic growth. The knowledge-based economy trades intellectual and access rights rather than physical products and ownership rights. Knowledge stimulates economic growth in three ways - as a source of innovation, as a necessary input to symbol manipulation and as a carrier of 'soft' interpersonal skills. It remains expensive and difficult to transmit: it is crucially a human attribute, reinforcing the centrality of humans in this new era. The operational definition of human capital used in TERRA2000 is:

> The knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well being.

It is produced from: innate competencies, aptitudes and attitudes; education, training and experience and physical, mental, emotional, social and cultural factors influencing human motivation and behaviour. The central activity of the project is the examination, through a combination of data analysis, modelling and analytic, interactive scenario development of the nature of the GNKS, the forces that shape its evolution, and the extent to which those forces are or can be made consistent with an appropriate definition of sustainability. Information consists of structured and formatted data that remain passive and inert until used by those with the knowledge needed to interpret and process them. The cost of replicating information is the cost of making copies. Knowledge (in any field) gives its possessors the capacity for intellectual or physical action - it is a matter of the cognitive capability to understand and use information, that is, to create meaning.

Knowledge is expensive to reproduce - cognitive capabilities are not all easy to articulate or transfer, and thus remain "tacit" – their transmission depends on master-apprentice or collegial relationships, and thus on social ties, generational contact and professional self-regulation.

Some knowledge can be codified - reduced to information by increasingly complex actions (using natural language, applying industrial design techniques to make a blueprint, creating an expert system, etc.) Codified knowledge becomes almost independent of human beings, and carries the implication that "the problem of memory ceases to dominate intellectual life." This is broadly what Nonaka and others refer to as 'Explicit' knowledge. The interplay of information, tacit knowledge and

[1] This is not wholly surprising: standard signalling models of education have inefficient equilibria and competition creates a Prisoners' Dilemma among students.

explicit knowledge leads to the process of creation of new knowledge (new meanings for information) that we call 'innovation'.

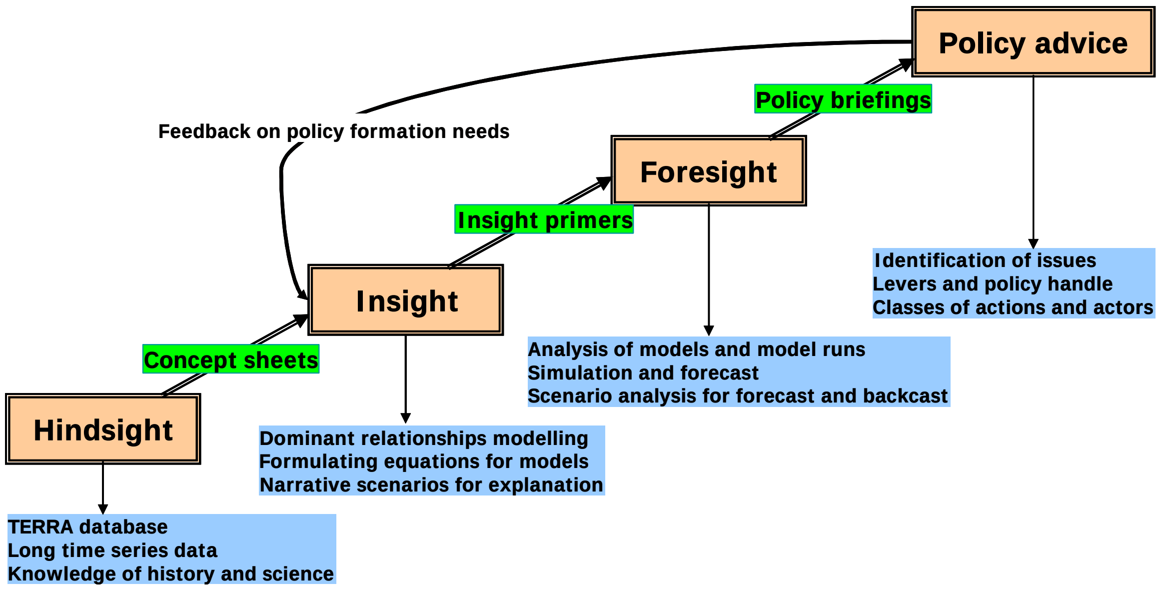
The GNKS is concerned with the acquisition, diffusion and application of new knowledge and thus with innovation. In fact, Castells thinks that the GNKS is characterised by its focus on how societies use knowledge to create new knowledge. This, in his view, is a process that amplifies itself, and that is what makes it unique in the history of mankind. Needless to say, the GNKS is a controversial concept (see also David and Spence, 2003); its changed dynamics and responsibilities challenge our societies' capacities for sustainable decision making, global governance, and adapting to a changing human habitat (the planet). Seen in this way, GNKS and sustainable development are closely related and a key research topic.

It soon became apparent that no single definition of knowledge could meet the conceptual demands placed on it. In addition, no unambiguous measurement of knowledge derived from available data would stand up to even the mildest econometric analysis. The balance of this section sketches the framework that defined our requirements for knowledge measurement. The perspective is theoretical – more explicit empirical findings and concrete policy proposals can be found in the various TERRA Reports, to which the "Story of TERRA" – in its long and short versions, serves as introduction and *catalogue raisonnée*.

3.2. The analytic perspective: from hindsight through foresight to insight

The project used three overlapping tools (modelling, scenario development and discourse) to explore the underlying issues surrounding the sustainability of the Information Society. The original idea was for each to produce a single output reflecting a unified, convergent perspective. It soon became apparent that neither the state of the art nor the consensus view of the underlying concepts would support this approach, and that the real objective was to clarify and explore the concepts and develop a set of tools and methods adequate to support a future balanced exploration of the issues. To provide necessary coherence, the project considered three broad themes (human capital, equity and growth and environmental sustainability). The world is uncertain and information is diffuse. To inform policy and discussions, various sorts of thinking/discussion aids, consistency checks and validation are necessary. In particular, understanding evolution of a complex system requires a combination of data, models and scenarios.

Model development and use took place on several levels. *Hindsight* is based on databases and statistical analyses, *insight* is based on models and scenarios describing the function and linkages of underlying mechanisms and *foresight* uses such mechanisms to project (not forecast) future evolution and the impact of policy under different circumstances.



The relationship between Information Society Technologies (ISTs) and their wider societal impact was elaborated by TERRA's linked series of narrative scenarios and numerical models concentrating on identifying and expanding the most crucial aspects of the picture. This Dominant Relationships Modelling preserves scientific integrity, modelling only that which may reasonably be measured or formalised. This is combined with a high degree of transparency (since policy recommendations will not normally be accepted, fruitfully debated or usefully acted on if they cannot be confidently understood by those to whom they are directed).

Analysis begins with statistical data summaries, high-level, aggregate and/or specific models and scenario and trend extrapolations which support detailed analysis and identify "things we didn't know that we knew." They also pose conceptual puzzles beyond the reach of formal – or at least numerical – models about e.g. commoditisation of intellectual property, diffusion of new ideas, chains of secondary innovation, coevolution of network connections and cooperative behaviour, etc. These simple models are at least explicit, easy to comprehend and (given appropriate assumptions) reasonably robust.

By contrast, the 'hidden features' of the GNKS were addressed through more detailed[2] and disaggregated analyses, based on complex methods and more sensitive to assumptions and other uncertainties. They are a way of investigating "things we know that we don't know."

Data[3] provide calibration, face validity and proportion. But their provenance and interpretation reflect definitions, coverage, collection methods etc. Models and scenarios unlock information and meaning hidden in the data. TERRA collected and used 'hard' (quantified, objectively measurable) and 'soft' (only measured through indicators and/or subjectively defined) data.

Models help to unlock latent tendencies in data, test understanding of system structure and dynamics, and present policy issues in ways that expose assumptions and rules of inference. Models can use and/or generate data, but not all models do so. Models in TERRA fall into three broad categories:

- *Computational models* of varying complexity, completeness and fidelity to empirical data (paradigmatic high-level *insight models,* strategic medium level *dominant relations models* and policy-analytic detailed *integrated models*);
- *Empirical models* to test specific hypotheses against real data and develop predictions from proven hypotheses. Predictive empirical models expose underlying – as opposed to apparent – trends and extrapolate them into the future under alternative assumptions.
- *Theoretical models* derive useful conclusions from starting assumptions and rules of inference.

These are neither disjoint nor fixed. As the perspective shifts from prediction to policy analysis, the tools evolve as well. Many of the phenomena tackled by TERRA are not measurable – some are not even quantifiable – so the models are (and should be) at different stages of development. It is no accident that the latter stages of the project saw an increase in paradigmatic and theoretical modelling; this appropriate for fundamental developments exposed as essential by computational modelling and accompanying scenario analysis.

Scenarios provide a common basis for discussion and analysis to ensure that progress towards understanding the strength and policy implications of the propositions is logically consistent, reasonably comprehensive, comprehensible and engaging for stakeholders, calibrated to data where possible, sensitive to hard and soft data and policy relevant. They are thus a tool for exploring knowledge and improving coordination.

TERRA scenarios were used as a framing device for describing the current situation, identifying trends and possible interventions, and making visible important criteria. This was particularly true of the primarily numerical Human Capital scenarios, which used explicit computations to calibrate the issues considered, quantify direct and side effects of specific policies and highlight attractive policy combinations. The Equity and Growth scenarios were more explicitly laid out along two critical dimensions in 'scenario space,' but also used dominant relations models for calibration. The Information Age Sustainability scenarios were described in welfare and environmental stress terms and scenarios developed by feasible trend extrapolation.

A further set of integrated scenarios were developed with the IFs for TERRA model to track possible futures from an empirical point of view. This analysis was built up from the necessary conditions for and spillover consequences of sustainability in all thematic areas. This therefore represents the 'virtuous corner' of scenario space.

Ultimately, the aim remains to support the interactive use of this set of scenarios in combination with the models and exploration tools. These elements provide a context for discussion to combine knowledge of participants whilst minimising impact of 'foregone conclusions.' Eventually, and beyond the bounds of this project, a more active approach is to use combined scenarios and tools to facilitate interchange among experts through gaming. At the current phase of scientific and policy development, the greatest contribution of these efforts is to shed light on the relevant complexities of the central concepts of Globalisation, Networking, the Information Society and Sustainable Development.

3.3. The sustainability perspective

In 1987, the United Nations identified sustainable development as a critical priority. This concentrated the world's attention on a set of related issues and problems, which had been recognised earlier, but in sporadic and specialised fashion. Put simply, the problem was that existing patterns of growth and development, while driven by apparently rational behaviour at individual, enterprise and even national level, produced aggregate effects that jeopardised not only the collective aspiration for adequate, equitable and fulfilling life for all, but even the very continuation of life on the planet. In order to deal with such a problem, it

[2] Theoretical models describe underlying mechanisms in detail; integrated computational models are detailed in scope.
[3] Data sources described in "Tools and Models Final Report" and references therein.

is necessary to recognise it at a collective level, to understand its dimensions and uncertainties, to identify the important actors and their motivations and powers, and to develop collective institutions (of whatever degree of formality) capable of supporting solutions.

The UN report identified three dimensions along which sustainability could be assessed: environmental (resource use and ecological impact); economic (provision and distribution of the means of sustaining life) and societal (including institutions through which we interact). Subsequent work recognises an additional, cultural dimension, has greatly improved our scientific understanding of the mechanisms and processes involved, generated masses of new data about the state and trajectory of world systems and has produced many policy and institutional suggestions. Some have been tried out and many more have been discussed. But the challenges of sustainability, far from receding, have sharpened and become more pressing. Moreover, despite the early and largely uncontested recognition that these problems (as a whole) are global in scope and require collective solution, increased awareness and knowledge have served more to exacerbate division and suspicion than to generate global consensus.

It is increasingly recognised that the environmental, economic, societal and cultural dimensions are important as a means of measuring sustainability and as domains within which human institutions operate. Assessment itself has advanced; in the beginning, sustainability was measured in terms of stocks of scarce resources, income, social capital, cultural products, etc. Despite early indications, however, we have not in general, run, out of these things. This teaches two lessons: that human ingenuity can often identify substitutes for scarce resources; and that the ownership and distribution of resources matters as much to human welfare as their absolute levels. We should be concerned with the availability of world systems to support life – this is a more general and technology-friendly concept than a stock-based definition. Moreover, the past three decades have thrown up a number of shocks to the system. Some reflect unforeseen events, though most result from unanticipated spillovers from one sustainability domain to another or rebound effects of past changes. Sustainability concepts and analyses based on availability need to be bolstered by considerations of resilience and policies need to be both robust and adaptive.

4. Knowledge, Truth and Belief

4.1. What Drives the Information Society?

The GNKS concept is built on several convergent strands. One which can be expected to have measurable consequences is the increasing information-intensity of economic activity. A crude map of places where knowledge shows up can be derived from a functional view of modern economies. In particular, we might distinguish:

- Inputs:
    - Non-produced (and hence non-renewable) inputs (raw materials, energy sources, etc.)
    - Renewable inputs
    - “Commons” inputs (inputs over which it is difficult to define property rights, and which are therefore both to mediate and to measure through the operation of markets)
    - Labour inputs
    - Knowledge inputs (codified, tacit and relational knowledge)
    - Produced inputs
    - Capital inputs (physical, human, financial), etc.
- Infrastructures
    - Markets
    - Networks (e.g. communications, transportation, energy)
    - Regulatory infrastructures, etc.
- Market sectors
    - Information-technology sectors
    - Communications sectors
    - Service industries
    - Manufacturing industries
    - Retail sales, etc.

Knowledge, in one form or another, pervades these. For instance, in the input sphere, beyond the measurable or otherwise direct knowledge inputs lie elements of technical know-how that determine input productivity, but which are not embodied in otherwise measured inputs. Many of these have traditionally been measured in indirect ways. At the macro level, for instance, the ‘Solow residual’ has been interpreted as a measure of the impact of ‘knowledge capital’ or an amalgam of information-related factors. At the micro level, the creation and dissemination of codified knowledge are often measured through patents or publications. Tacit or embodied knowledge is measured through indirect inputs such as human capital estimates based on schooling or proximate outputs such as labour and physical capital input productivity or certified skill levels. Relational knowledge is almost always measured as a residual (e.g. x-efficiency) or in structural terms (descriptions of networks or hierarchies).

4.2. Technological change and R&D

Many papers address R&D and technical change in growth: the general relation between productivity and technological performance is well known. The core concept is the knowledge stock. This is not simply defined, but may be considered to be global and to encompass the sum of ideas relating to basic scientific and non-scientific understanding and their applications in technological and non-technological activities. This global knowledge stock may be expected to increase over time through many ways, most notably through: world scientific activity; other R&D activity; and experience and the use of knowledge (thus overcoming any tendency to rely on the outmoded linear model of innovation).

To some degree the forces that drive additions to the scientific knowledge stock - essentially peer esteem - may be very different from those driving use of that knowledge - expected private financial returns. There is not necessarily a close relation demand and supply.

Nations, firms or individuals draw on the global knowledge stock. As they embody such knowledge into their economic processes so output and productivity increase and growth proceeds. Use of knowledge can come about through embodying ideas in products and processes (including new management methods) or by using products and processes in which others have embodied knowledge. Accessing and using knowledge stocks is the process of technical change.

Past literature suggests that technical change thus defined is at least a major driving force of growth and productivity. Knowledge is considered to be *non-rivalrous (*use by one does not prevent its use by another). In addition, use of knowledge is not zero sum: if all used the knowledge all *could* be better off. However, there are advantages to being ahead. Having a technological lead, using later knowledge or using it more effectively, yields extra benefits whatever the level of technology. Leaders will typically[4] be richer than followers. If a follower catches up, the follower will become better off but this will happen partly at the expense of the leader's prosperity (Krugman, 1995). A follower who falls further behind will become worse off. For an individual country therefore, growth and productivity benefits arise through technical change, but having a technical lead means even greater levels of output and productivity for the leader than if all countries had the same technological level.

For an individual country technical change may involve catching up or, for countries on the frontier, maintaining a position on a moving frontier. Backward countries that can move towards the frontier have greater growth opportunities than those already on the frontier. For example, until recently Japan was able to grow very fast as it caught up - its growth has now reduced considerably. However, catching up will not necessarily enable countries to pass those already on the frontier; catch-up may reduce leaders' output levels as their technological lead is reduced.

The key issue is how successfully to access and utilise global knowledge stocks? Jones (1998) emphasises the importance of infrastructure and incentives (for example, low crime rates). This suggests that economies where private incentives are strong, risk capital is available and education levels are high have an advantage in assimilating and utilising knowledge.

At a more detailed level:

- If *knowledge is tacit* then experience matters and success breeds success.
- If *complementary inputs* are important to knowledge assimilation and use then high skill levels in the work force and perhaps clusters will be important.
- Own knowledge generation activity (R&D) may be necessary to understand the knowledge available in the global pool.

Effective IPR policy may be essential to benefit from domestic additions to the global knowledge pool. If the knowledge pool is global, why should any country bother to spend on R&D rather than free-riding? The reasons are that in addition to adding to world knowledge stocks, for a single country or region R&D:

- Facilitates understanding and assimilation of other knowledge[5] in the world stock;
- Creates labour skills that enable effective use of knowledge; and
- Enables that country or region to be first to acquire and use additions to the world stock of knowledge, thus securing the first move advantage.

Will greater R&D yield higher output, productivity and growth in a given country? The literature accepts that R&D yields higher growth and output levels, but there is considerable controversy as to whether such increases persist – some recent growth shocks have died away quickly. On the evidence, R&D matters (at least for a while) but not only R&D will matter. In many areas of economic activity, Europe may well not be on the knowledge frontier and catch-up is feasible. R&D can contribute to this, but other catch-up policies may be at least as important. In other areas, R&D may enable Europe to lead

[4] Some situations show "second-mover advantage," but we do not go into these here.

[5] Cohen and Levinthal (1989) argue that R&D has two faces. It both develops new knowledge and also enables firms to assimilate knowledge originating elsewhere.

more effectively and improve performance. To the extent that R&D means earlier and more extensive use of technology, Europe will benefit.

What else matters? Undue or single-minded emphasis on R&D places excessive emphasis on the generation of technology rather than its use. As IPR protections and persistence of technological advantages weaken, use or diffusion increase in importance. R&D may affect them, but so do other factors including:

- Availability of long-term finance for technological investments;
- Availability of start-up capital for new firms;
- Availability of skilled labour;
- Attitudes to risk;
- Macroeconomic conditions;
- Information spreading mechanisms; and
- Tax and policy environment.

However, greater R&D or faster catch-up will not necessarily measurably increase growth. To some degree at least, what matters is performance *relative to competitors*; if they also speed up Europe may be running faster to stand still. A wealth of data shows how the increase in world R&D. A region that wishes to retain a technological lead may therefore have to *increase* R&D in order just to stand still. Jones (1998) notes that in the US between 1950 and the mid 1990s the fraction of the labour force engaged in R&D increased 3-fold, but average US output and productivity growth rates are no higher today than from 1870- 1929 (one should note that Jones does not attribute this to the cause stated here).

This has two additional ramifications. First, it suggests that *growth* in the supply of innovators is needed to retain a growth advantage (not merely adequate *levels* of supply, as argued by Schumpeter). Second, equilibrium reasoning casts doubt on scenarios of sustained widening gaps between technological leaders and followers: fruits of R&D investment will tend to be dissipated by competition for the technological lead, and in the long run the only reliable benefits are global.

Increased investment in R&D and related activities – while possibly generating higher output - may not necessarily generate increased consumption and welfare.

OECD data place European countries some way down international productivity growth league tables; they have probably been falling further behind in terms of (R&D):(GDP). There is thus significant opportunity for Europe to do better in terms of both R&D and technology diffusion. It is unclear what is actually required - whether Europe requires more R&D or a higher (R&D):(GDP) ratio, absolutely or relative to competitors.

Finally, seeking more R&D or faster diffusion is very different from finding a mechanism to do so. Much academic technology policy literature is microeconomic and primarily concerned with market failure – it asks whether government intervention *can* reduce market failure and increase welfare. The approach here is more macro orientated and driven by international comparisons. It is not necessarily the case that poor comparative international R&D performance is the result of market failure or that policies aimed at repairing failing markets will help.

The list of policy instruments is well known to all:

- Tax incentives to R&D (or the less-common alternative of levy grant schemes)
- Policies to make capital markets more long-termist (e.g. modifications to anti-trust legislation) or turnover taxes and extensions of venture capital.
- Improved skill supplies and further investment in trained and scientific personnel.
- Encouragement of inward investment to transmit best practice.
- Risk-shifting launch aid schemes
- Macroeconomic stability (although to date this has not worked well)
- Effective IPR policies to enable early domestic exploitation
- Reconsideration of defence and high-tech bias in government R&D spending.
- Improved access to scientific expertise for potential knowledge users.

There is no easy fix, and these policies must be integrated with others - some on a global scale. No literature suggests that raising the rate of technical change in an economy, especially mature economies such as Europe or the US, can be achieved quickly or easily.

4.3. A policy rethink: propriety of intellectual property rights[6]

The work in TERRA leads inevitably to the largest area of reinterpretation of existing understanding arising from GNKS - IPR. They come to the fore at all times of technological change (Jefferson and McAulay defined the state of patent law at the beginning of the second Industrial Revolution for instance) so it is hardly a surprise that it should be central to the IST story; what is perhaps more surprising is the close relationship between the current debate and the debates of the 19th century.

> "Why have property? Property feels right to many of us because of a sense that each of us should own the fruit of our labour. But this is at least not the whole story, because some property - such as land - wasn't created by its owners. Say there's a large stretch of land that's commonly owned, such as the West of the U.S. once was. The government decided to open the land for private ownership. It didn't have to do it; it could have kept it as a giant park, and no-one's property rights would have been harmed. But it gave or sold the land to people who didn't create it, thus limiting the freedom of action of all others. The reason for this was incentive: If people have the right to exclude others from their land, they'll have more incentive to invest effort in improving the land - build homes, plant crops, and so on...So far, the argument tracks copyright and patent law quite well. The theory of intellectual property is likewise that giving people the right to exclude others from new works or inventions will give people an incentive to invest effort in creating and inventing.[7]"

The Global Network Knowledge Society runs on ideas and information. Instead of deeds and fences, it has copyrights and patents. We tend to regard ideas as public goods in need of protection by special ownership rights; and *exclusive* IPR as both necessary and appropriate for innovation. However, there are grounds for arguing that neither of these propositions is true.

An idea in my head has value in use (I can exploit it to make things) or exchange (I can communicate it to those who might use it). Before I do these things, it is a private good - rivalrous (since only I can use it) and excludable (since I can keep schtum). Communication is production - using the private inputs of the idea and time to it produces a new private good (the idea in another head). Ideas embodied in our minds are even more private than a house or plot of land, which would at least survive if the owners died.

In contrast, disembodied abstract ideas[8] lack economic value. Economic valuable inheres in a copy of an idea[9] (hence mimetic evolution) and thus in rights. If two copies of an idea are separate entities, use of one does not affect use of the other. This does not make them public goods any more than use of a CD affects use another copy of the same CD. Oddly, IPR do not merely replicate property rights for 'real' property, but go well beyond. If I sell you a car I would not seek to tell you where you could drive it or for what purpose - but IPR do[10]. Your right to control *your* copy of your idea does not need a great deal of protection. IPR are concerned with your right to control *my* copy of your idea.

IPR may be seen as a (default) contract rather than a right, but such a contract would normally be regarded as illegal, inefficient or unethical. In most other contexts contracts prohibiting reuse[11] would be anticompetitive and *illegal*. IPR could be seen as a voluntary 'default contract' that saves transactions costs. But such contracts are difficult and costly to implement or enforce. This *inefficiency* is perhaps the most important reason for limiting attempts to restrict subsequent rights of buyers of ideas. Compare codified with tacit knowledge[12]; this is exactly why people can rent but not sell their labour. Labour and ideas are economically valuable things attached to persons, so enforcing sales contracts is unethical, intrusive and very expensive. Software or books become your private property once you have bought them and the seller's other rights are exhausted at point of sale. Where this is inappropriate[13], you could lease ideas, borrow them from the library, etc. The intrusiveness required can be extensive: in Bright Tunes Music Corp. v. Harrisongs Music, Ltd. [420 F.Supp. 177 (1976)][14], the court ruled, "His subconscious knew it already had worked in a song his conscious did not remember... That is, under the law, infringement of copyright, and is no less so even though subconsciously accomplished."

This is one reason why the IPR debate is closely linked to the privacy debate. 'Software audits' and enforcement actions against 'pirates' are intrusive, costly and often paid for by third parties (taxpayers, ISPs, computer manufacturers). The voluntary issue is whether all affected parties have a say. If you buy software and break your agreement by selling it, they

[6] Some of these ideas are developed at greater length in Boldrin and Levine (2003), Tesch and Descamps (2003) and Cave (2003).
[7] Volokh (2003).
[8] Ayres and Warr (2002) analyse the role of such abstractions in neoclassical growth theory.
[9] See Blackmore (2000) for an exposition of the evolution of ideas through copying.
[10] This is largely limited to the IPR system *per se*. As Botterman, *et. al.* (2001) point out, such restrictions are not allowed in e.g. Freedom of Information requests.
[11] David and Spence (2003) discuss the impact of EC Database Directive re-use prohibitions.
[12] See e.g. Cave, Hughes and Mesarovich (2002).
[13] For instance, in recognising the moral right to be identified as author of a work or to make limited use of the idea, where the purchase transfer of right is 'too big.'
[14] Cited in Boldrin and Levine (2003).

buyer is still bound by the original agreement. If you do this over my network, I am liable for violating a contract I never agreed to. There seems little justification for the IPR laws as written and enforced.

But what about the incentive argument? We don't usually look beyond the terms of sale for incentives - we want innovation and development in most areas of commerce, but don't rely on exclusive state-granted monopolies. The above views knowledge like machines used to produce useful things. If we could scale knowledge up or down we could simply abolish IPR and harness the power of free enterprise to determine the correct amount and allocation of knowledge. Socially valuable ideas would be used as widely as was appropriate. There would be no more need for IPR than for laws allowing the makers of breakfast cereals to control how we chose to eat them. But knowledge is not neatly divisible - two half-ideas do not make a whole one.

Can the sale of ideas without monopoly power sustain innovation[15]? Here is a standard argument[16]: "A good argument for copyright in music. You've just earned a $250,000 advance for your rock band, and you don't see any real profit from it...without copyright income the artists would be deeply, deeply in debt, or more realistically would never have the chance to record in the first place." But the innovation took place despite poor rewards, weakening the *a priori* case for monopoly. Moreover, the essential indivisibility is the first copy cost - which technology has drastically reduced - as it reduced the costs of subsequent (even 'pirate') copies. In fact, many people could modify existing work or create their own.

What checks this flow of innovation? IPR. One cannot begin by modifying existing work because it is locked up for the foreseeable future - the shoulders of giants[17] are fenced off. If they want to make brand new material, they have a steep entry barrier, compounded by the allocation of access to distribution channels on the basis of distributors’ expected future IPR income[18]. This biases innovation in favour of profitable 'product' and, in turn, against really original output. But really new output is the only kind that can avoid the existing 'protections.'

Ultimately, these considerations suggest that "intellectual property" debate is not about creators’ rights to the fruits of their labour, nor the incentive to create, innovate or improve. It is about the "right" to preserve existing business models. In 1939, Robert Heinlein’s judge in Life Line observes:

> "There has grown up in the minds of certain groups in this country the notion that because a man or corporation has made a profit out of the public for a number of years, the government and the courts are charged with the duty of guaranteeing such profit in the future, even in the face of changing circumstances and contrary to public interest. This strange doctrine is not supported by statute or common law. Neither individuals nor corporations have any right to come into court and ask that the clock of history be stopped, or turned back."

5. Issues for further discussion

This work raises a series of issues for further discussion. 1. Distribution measures are as important as aggregates for sustainability analysis, and should consider both capacity (Gini) and isolation (Fields). 2. Dominant relations models based on linked sets of indicators (e.g. ASA) can treat phenomena like dematerialisation and immaterialisation at a high level. 3. Integrated 'world models' (e.g. IFSfor TERRA) can deal with a rich array of direct and spillover effects and provide both space for policy exploration and a chance to evaluate new ideas of mechanisms *in situ*. 4. Measures for policy evaluation should resemble opportunity costs and take account of distance: for instance, a measure of people with access must be complemented by measures of people passed by trunk lines or within range of transmitters or DSL switches; measures of skills should consider both current knowledge and the ease of adding to or changing it. 5. Network structural measures (path lengths, centrality, clustering, etc.) applied to people, institutions, ideas, etc. are very useful in measuring knowledge creation, use, dissemination and depreciation. 6. Intellectual property rights data should be used to construct 'spatial' or network maps of rights (e.g. patent thickets and clusters) and take account of licensing (and licence revenues) and renewals. 7. Measures of IST deployment (esp. in eGovernment, eHealth, etc.) that substantially change the allocation of risk and responsibility should go beyond activity measures to consider effectiveness in meeting needs.

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[15] See Tesch and Descamps (2003) for a policy proposal based on this insight.
[16] Cowen (2003).
[17] Scotchmer (1991) argues in favour of modification, re-use and cumulative innovation.
[18] Recently, exceptions have begun to emerge in the world of peer-to-peer music sharing (Times (2003)) and open-source software.

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