Integrated Assessment
2002, Vol. 3, Nos. 2–3, pp. 151–159

1389-5176/02/0302–3-151$16.00

Sustainability and Economics: A Matter of Scale?

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ABSTRACT

Sustainability is a global issue concerning future generations, but steps towards sustainable development must also be taken at the spatial scales of regions and at the temporal scales of individual lives. Different scales matter in social networks and in cultural realities, too. The fact that relatively small regions can dominate global markets for products based on continuous innovation points to the accumulation of a specific social capital in these regions. This resource is a club good at the regional scale. Similar goods exist at national scales. Their development depends to a considerable extent on expectations that play a very different role in the short and in the long run. In the former, the efficient market hypothesis seems a reasonable approach. In the latter, very different approaches need to be developed. Understanding how processes at the regional, national and global level interact in the short and in the long run will be vital for a successful management of the transition towards a sustainable world economy.

Keywords: sustainability, scale issues, temporal scales.

1. INTRODUCTION

Over the last decades, it has become increasingly clear that the world economy is on an unsustainable path. Is a transition to a sustainable society possible in the 21st century? In other words: can our grandchildren live in a society that would look at global environmental disruption no more as a threat to its future, but as an expierence of the past? The question is as urgent as it is difficult. A sustainability transition, if it will happen at all, will be a complex process, involving many different scales – in spatial, temporal, and institutional terms. It will take a long-lasting process of integrated assessments to develop an awareness of where we stand in relation to this challenge, and where we can – and cannot – go.

These assessments will need to keep the spatial, temporal and institutional scales of everyday human life in sight if they are to be practically meaningful. These are the scales where it makes a difference whether two people talk to each other from a distance or whether they are so close as to be able to touch one another. They are the scales at which it makes a difference whether we leave home for a weekend or for a two weeks holiday, at which we make career choices, develop diet habits, go for a walk or take a nap.

The sustainability transition cannot be grasped at the scales of everyday life only. Integrated assessments dealing with the sustainability transition need to take into account an ‘‘astronaut's perspective'' as well. The diet habits of billions of people are geared to changes of the whole earth system, and so are their choices about which transport systems to use, where to live, etc. Switching between different scales of analysis can result in amazing journeys, however.

A simple triangle suffices to illustrate what kind of surprises can arise.[1] As Figure 1 shows, on a Euclidean plane, summing up the angles of a triangle yields a straight line, or an angle of 180°. In the figure, lines c and c* are parallel, so that the angles β and β* are equal, as are the angles α and α*. This fact is hard to prove, however, and may rather be introduced as an axiom.[2] Our experience with pencil and paper, or with rigid structures that we may lay out on the ground, shows that such axioms actually work in such settings – they lead to sound inferences and sound constructions, they help us to make accurate observations and to engage in successful actions.

Now consider a triangle on a sphere. Here it is perfectly possible to construct triangles with three right angles. On the surface of planet earth, one may imagine a triangle with one angle at the North pole and the other two on the equator, the

[1]The following argument builds on Putnam [1].
[2]An alternative route would be to introduce as an axiom that the angles of any triangle sum up to 180° and to deduce the equality of angles α and α*.

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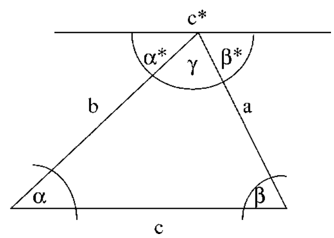

Fig. 1. Sum of angles in a Euclidean triangle.

distance between the latter two being just one quarter of the equator. At the scale of human individuals living on the surface of the same earth, however, Euclidean geometry works perfectly well.

Of course, one may be tempted to say that it works only as an approximation, but this misses the point. If a designer wants to cover the floor of a living-room with triangular tiles she cannot improve the design by making calculations with triangles whose angles sum up to a tiny little bit more than 180°. On the other hand, if trajectories of three satellites were computed on the basis of the assumption that they cannot be all orthogonal to each other, this would lead to nonsensical results.

So far we have considered spatial metaphors, but the argument extends to temporal scales. When singers perform an opera, it is perfectly – not approximately – clear what it means for them to start a duet at the same time. When astronomers study two supernova explosions, they must come to terms with the fact that these explosions may be simultaneous if observed from one point in space and not simultaneous if observed from another one.[3]

Temporal scales are of additional interest when they relate to non-linear dynamics. Complex patterns may emerge and fade away at different scales, sometimes yielding stable structures at one temporal scale and chaotic dynamics at another one (see Christiansen and Parmentier [2], Sterman [3]).

Scale issues are not limited to physical reality, they arise in mental structures, too. A domain of discourse may have a logical structure under which it is possible to assess for any single sentence whether it is true or false, but not for all sentences at once.[4] Like a rug in the carpet, the domain of uncertainty wanders around whenever new certainties are found. Even logical laws may hold at one scale of analysis and fail at another one.[5]

Spatial, temporal, and logical scales interact if one considers an integrated assessment incorporating a component of demographic change. At one scale a population can be represented by fairly simple rates of fertility, mortality and net migration. At another scale, the decision of an individual to (try to) have a child is a highly complex decision, and modeling this decision-making process is incredibly difficult. In some situations, it may be perfectly sufficient to understand the net result of these complex decisions at a global scale (e.g., through aggregation and projections of national census data). However, in other cases it is important to analyze this decision-making process at an individual level in order to understand the mechanisms triggered by different policies.

Different laws may hold at different scales, and one can try to establish rules for the transition between these different domains.[6] Even in everyday life, such transitions are widespread, as we sometimes realize when switching from one social setting, e.g., an empty bus, to another one, e.g., a crowded baseball stadium. Of course, sometimes huge scale changes are possible without inducing any change in relevant patterns, laws, etc.: it was the great triumph of Newtonian mechanics to show that stones and stars follow the same laws of motion.

But sometimes moving from one scale to another comes close to traveling between different worlds. While traveling, we may encounter a twilight zone of ambiguity. But as the distinction between day and night is perfectly sound although no clear-cut boundary separates the two, so the distinction between small and large scales may often be perfectly sound even if a gradual transition between them is possible. And of course, more than two scaling levels are relevant in many domains of inquiry.

Perhaps, little more can be said about scale issues in general. Rather, it seems necessary to consider such issues case by case. In economics, there are many instances of scaling issues – the micro-macro problem is one of the big challenges of our discipline, returns to scale one of its classical topics (see Gold [5]). We consider the latter in a brief overview of orthodox economic methodology and its core assumptions about returns to scale. Then, we will focus on two particular instances of scaling issues in economics that are especially relevant for the sustainability transition: the role of innovative regional economies on global markets and the role of expectations in the short and the long run.[7] We will conclude with a few remarks about the relevance of scale issues for bringing about a sustainable world economy.

2. RETURNS TO SCALE

According to a famous definition, economics is the study of the allocation of scarce resources.[8] Integrated assessment is

[3]This is the kind of reasoning which differentiates relativity theory from classical mechanics. It involves a further version of non-Euclidean geometry, now couched in four-dimensional "space."

[4]Such patterns are known from quantum logic. There is no reason why similar structures should not be widespread in the fabric of human knowledge.

[5]This led mathematical intuitionists to argue that the logical law of the excluded middle holds for finite sets, but not necessarily for infinite ones.

[6]This is a major issue in geographical research, ranging from landscape ecology to remote sensing (see Wong and Amrhein [4]).

[7]Both shed some light – or perhaps twilight – on the micro-macro problem.

[8]"Economics is the science which studies human behaviour as a relationship between (given) ends and scarce means which have alternative uses." [6: p. 16].

multi-disciplinary, policy-relevant research that is typically carried out on complex environmental issues. A key problem with the environment is that what once was abundant, now is scarce. Economics is thus one of the core disciplines of integrated assessment.

Economics is also a controversial discipline. This is partly because the discipline has taken a unique route in its quest for knowledge accumulation and partly because other researchers do not always take enough time to understand economics and economists are not always patient enough to explain their ways. In contrast to other social sciences, the defining methodological characteristic of orthodox economics is mathematical rigor.[9] That is, an economist starts with a series of basic assumptions (treated as axioms, first principles, laws) from which higher order characteristics are deduced. Rigor is assumed to be a prerequisite for true understanding of economic phenomena.

In the early days, the basic assumptions were rather limited in number and scope. The predictive power was, therefore, rather limited as well. Over the years, however, the set of basic assumptions has been extended and refined so that economists now have a clearer understanding of many observed phenomena in economies.

Few non-economists are aware of the advances of orthodox economics. In fact, a lot of people have a rather outdated image. Applied economists, the ones that enter into the discussion with other disciplines, often rely on older methods, assuming perfectly competitive markets, unboundedly rational actors, full employment of labor and other resources, and so on. This is sometimes because of convenience. More often, however, this is because it was shown (in some paper unknown outside the economic community) that, for this particular environmental application, the older, simpler, more convenient assumptions lead to the same conclusions as do the newer, more complex, more elaborate assumptions.

There is no ''scale theory'' in economics, in fact, scale is hardly treated as an issue in economic textbooks.[10] At the same time, scale issues are pervasive, and labelled, treated and analysed in so many ways that a survey would be an enormous task.

Standard economic models use production functions that have a property known as ''constant returns to scale.'' That is, the production function is such that if all inputs are multiplied by a factor λ then output is multiplied by the same factor λ. If output increases by less than a factor λ, we speak of decreasing returns to scale. If output increases by more than a factor λ, we speak of increasing returns to scale.

The standard assumption of constant returns to scale has major implications for the influence of scale issues in economic models.[11] One implication is that the structure of the economy is essentially scale-independent. This is quite convenient. It is often possible to use representative consumers and producers, because heterogeneity in size does not matter. It is possible to ignore stochasticity, because temporary size changes do not matter. Another implication of the assumption of constant returns to scale is that the modelled economy does not have a spatial structure. As size does not matter, agglomeration does not matter either. A constant returns to scale economy is an economy without cities. Finally, constant returns to scale imply that specialisation does not pay. Starting from the same initial conditions, every firm and every country produces the same, broad range of goods and services.

The world of decreasing returns to scale does not differ fundamentally from the constant returns to scale world. In fact, the two go neatly together, where the assumption of decreasing returns to scale explains why inputs that are in principle substitutable (e.g., capital and labour) are in practice observed together.

The main reason why standard economic models assume constant and decreasing returns to scale is rigor. The analytical and numerical tools available to the pioneers of standard economics did not allow them to explore the consequences of alternative assumptions, particularly that of increasing returns to scale. With progress in mathematical and computer power, less restrictive assumptions have been explored, and the exact role of the original implications has been considerably clarified.

The world implied by the assumption of increasing returns to scale is radically different. Increasing returns to scale invoke (often local) positive feedbacks in the economic system. This brings strong path dependence with it, as there are asymmetries between growth and shrink rates. One ignores heterogeneity and stochasticity at one's peril with increasing returns to scale, as size – and thus random variations in size – matter if growth rates depend on initial size. Agglomeration and specialisation effects can be modelled using the assumption of increasing returns to scale.

[9] This is not to deny that other social science disciplines have produced gems of mathematical rigor. A case in point is the work in linguistics inspired by the correspondences between the idea of a grammar and the concept of a Turing machine (see Martin-Vide [7]). But the community of linguists – perhaps to their advantage – has always cultivated a methodological pluralism which includes historical, interpretive and other approaches.

[10] One would find reference to ''returns to scale,'' which is a property of the production function rather than an issue of scale. The common assumption of ''constant returns to scale'' does have major scale implications, which are treated below.

[11] At first sight, the economic notion of scale is one of speed: what varies is the amount of goods produced per time unit. Of course, this influences the stock of durable goods available. In chemistry, a similar distinction arises between fast and slow reactions with their effects on concentrations of different substances. In climate dynamics, atmospheric processes are fast in comparison with oceanic ones, again with implications for concentrations of various substances like greenhouse gases. In economics, greater production often goes along with a greater extent of the market, both in financial and in geographical terms. In this sense, the economic notion of scale is more than just a temporal one.

A dynamic variant of increasing returns to scale is learning-by-doing. Learning-by-doing means that experience gained with production today leads to lower average production costs tomorrow.

The assumption of constant returns to scale goes hand in hand with the assumption of perfect competition. Increasing returns to scale, however, reduces the number of competitors and so leads to forms of imperfect competition. Vice versa, the profits generated in situations of imperfect competition may activate increasing returns to scale. If not, newcomers will enter the market until competition is perfect.

In sum, the assumed properties of the production function (known as ''returns to scale'') have a profound effect on generic scale issues in economics. If the production function has constant or decreasing returns to scale, scale does not matter. The economy looks the same through binoculars and a magnifying glass. On the other hand, if the production function has increasing returns to scale, scale matters in the economy. Standard macro-economic models – the type usually used for integrated assessment studies – assume constant and decreasing returns to scale.

If one zooms in at smaller scales, research questions and methodologies change. The simplified assumptions made to make large-scale economic models work are obviously invalid at smaller scales. Full information, optimising behaviour, divisibility of goods, continuous substitutability, and flexible labour markets have no place in micro-economics, although they do in macro-economics.[12]

The question is, of course, does the detail of the small scale influence the patterns of the large scale? The answer to that question lies in the dynamics of the system. In a considerable number of cases, research has shown that there is no devil in the detail. In other cases, the jury is still out. We investigate two of those below.

3. INDUSTRIAL DISTRICTS IN THE WORLD ECONOMY

Globalization is not a new stage in the development of economic life, it is the intensification of a pattern that characterizes modern society since its beginnings. At the end of the Middle Ages, the ability to transcend national boundaries and to span the whole globe set the modern economy apart from older ways of life. This ability was based on two interlocked socio-cultural arrangements: open markets and specialized professions.

[12]For a thoughtful reflection on the complex relations between micro- and macroeconomics, see Hahn and Solow [8]. One implication of their work is that temporal scales present the bigger intellectual challenge for economic analysis than varying scales of production. We will discuss temporal scales in the section Back to the Future.

Of course, most actual markets are not completely open. They have entry barriers, sometimes quite high ones. But these can be overcome in perfectly legitimate ways, and this sets modern markets apart from typical structures of, say, feudal societies. And of course, economic activities are by no means always performed in a professional style. Unskilled labor plays a very important role in the history of capitalism. But without the skills provided by specialized professionals geared to a body of scientific knowledge, no global transport infrastructure and no industrial production system would have emerged, let alone a global culture sharing the music of Bach and the art of making pizza.

By now, the life of most, if not all human beings is interconnected via the global economy – be it through a direct or a very distant indirect connection – and they know it. What is surprising, then, is how important local conditions remain for economic activities. Silicon valley is a remarkably small area compared with the global reach of its products, and the same holds for the Hollywood movie industry. Since several centuries, the City of London is the premier location for financial activities in Europe – technological revolutions, wars, the breakdown of the Empire, and the rise of the Dollar did not overcome this amazing local singularity.

Since Marshall's attempts at understanding the role of industrial districts in terms of localized positive external effects, many models of regional economies have been suggested and new models will now doubt be proposed in the years to come [9–11]. For our present purpose – looking at scaling issues in view of the sustainability transition – two points may be emphasized.

First, successful regions in today's global economy share some good that is neither public nor private. In economics, this distinction is usually drawn in terms of exclusiveness and rivalry: a private good is one from whose use others can be easily excluded and whose use by one agent reduces the quantity available for use by other agents. If you put a piece of cake on your plate, it is not trivial for me to grab it; if you eat the cake, I cannot eat it anymore. On the other hand, it is hard for me to exclude you from using the English language, and if you do use it, it is by no means less available for me.

There is something about places like Silicon valley or the City of London that looks like a public good from inside these places: firms operating there can hardly be excluded from it, and by using it, they don't make it less available for their competing neighbors. That something may involve a contact network, a set of procedures, an evolving body of knowledge, shared facilities for producing some kind of goods, etc. Looked at from the outside, however, it looks like a private good: outsiders are excluded from its use, and if they were not, they would impair it. The kind of social network evolving over centuries in the City of London would break down if all of a sudden it had to involve ten times as many members.

This resource is a kind of club good.[13] Club goods are defined as similar to public goods up to a point: use of the good is non-rival only up to a certain number of users. And the first point to note about today's successful regional economies is that they do share some kind of regional club good. The regional scale seems due to basic features of human existence – the importance of face-to-face contacts, the changing character of conversations when more than a certain number of people is involved, the distance that can be covered in a few minutes by walking, the combinatorial explosion of possible binary relations when a social network grows in size, etc.

The second point to note is that regional club goods not only can make certain activities less costly than similar activities would be elsewhere, but that they can also greatly facilitate on-going innovation processes. Taken together, these mechanisms bring about the tremendous competitive advantage that some regions can build up over time. For newcomers, it is extremely difficult to challenge such regions, because building up a similar club good elsewhere takes time, is costly and involves a serious risk of failure. The incumbent region can finance continuous investment in its own club good out of the rent that the competitive advantage allows it to collect. This can literally mean that landlords in the incumbent region fund the kind of social life that maintains the regional club good. As a result, incumbent regions are advantaged in their specialization both by Heckscher-Ohlin kind of trade based on static comparative advantages and by monopolistic competition based on dynamic innovation rents as analyzed by endogenous growth theorists.

A similar analysis can be applied at the national scale, too. From a global point of view, the nation state sometimes looks more like a provider of club goods than of the pure public goods that are sometimes invoked to justify its existence. After all, there are national institutions, infrastructures, cultures and identities. In the course of history these can crystallize into shared national resources that confer competitive advantages in specific fields. From time to time nations are challenged in their economic specialization, and then their future will depend on whether they are able to either renew their existing competitive advantage or to build up another one in a new field [12].

At the global level, it is clear that so far only Western Europe, North America, Japan, and Australia have been able to firmly establish a capacity to generate economic innovations – personal computers, mobile phones, weather satellites, color TV, container transport, etc. – at a sustained rate [13]. Parts of South-East Asia, the Middle East, Eastern Europe, and Latin America seem able to absorb these innovations in processes of economic growth still driven more by capital accumulation than by technical progress. But the large rest of the world misses out in the fierce competition characterising todays global markets. This competition is a very different animal than classical and neo-classical perfect competition, but it certainly has little mercy with those who don't have the regional and national club goods required to innovate at the pace it requires.

With regard to the sustainability transition, this is a worrying situation. Take the global energy system.[14] Currently, about 95% of all commercial energy worldwide is produced by burning fossil fuels. In the coming decades, world population is bound to increase, mainly in those parts of the world that have a hard time in generating the innovations that are driving today's knowledge economy. At the same time, one would hope that these very parts of the global economy be the ones enjoying the fastest growth in income per head, so as to overcome the scandalous inequality of income across the globe. Sustainability is not meant to consist only in environmental constraints, it is meant to balance environmental with economic and social concerns. How then can one envisage a transition towards a more sustainable energy system under such conditions? This will be impossible unless new dynamics of economic development set in at the global, national and regional scales.

4. BACK TO THE FUTURE

For the purposes of integrated assessment, temporal scales of analysis are as important as spatial ones. For economics, they may actually be even more important. Economic dynamics is often analyzed in terms of a single intertemporal equilibrium path. This has been done by Ramsey [15] for a one-good world, and Nordhaus [16] has used a variant of Ramsey's scheme to analyze optimal climate policies in the long run. Arrow and Debreu [17] have suggested an intertemporal equilibrium for a world with many goods – the intricacies of such a world, however, lead to a much less suggestive picture than the one-good case. To maintain that picture, computable general equilibrium models are usually framed in such a way as to reproduce the basic dynamics of a one-good world.[15]

In the full-blown many-goods case, intertemporal equilibrium would allocate resources over time in the same way as it allocates them among sectors at any given point in time. A myriad of own-rates of interest for different goods at

[13]The role of clubs in the history of the City of London invites a footnote about how appropriate it is to consider club goods when studying regional economies.

[14]See the discussion in Imboden and Jaeger [14].

[15]Nordhaus and Yang [18] is a good example. Two main devices preserve the simple dynamics of a one-good world. First, a representation of investment which treats capital goods as some sort of homogeneous jelly which can be transformed costlessly in different kinds of infrastructure. And second, a representation of demand which eliminates income effects resulting from the production of different goods.

different moments in time must then result.[16] It takes a lot of faith (if not plain ignorance) to subscribe to the assumptions needed to blend them into an overall rate of interest ruling intertemporal capital markets.

It seems much more sensible to build on the distinction between two scales well-known in economics: the short-run and the long-run. As with the triangle discussed in the introduction, very different patterns prevail at these two different scales – but now it is temporal, not spatial scale that matters.

From a management point of view, short-run decisions are about how much to produce in order to serve actual demand on present markets. For the purpose of short-run decisions, production capacity and available technology are treated as given – because to modify them is a long-run process. Long-run decisions are about how to meet not actual, but expected demand. In long-run decisions, various kinds of fixed capital goods are purchased and produced in view of future demand which is not yet effective on present markets.

When studying long-run economic dynamics, supply and demand for goods traded on actual markets may be assumed to operate at equilibrium levels because their adjustment via price mechanisms is much faster than the development of various kinds of fixed capital relevant for long-run economic dynamics. As a result, at each moment in time one gets a temporary general equilibrium contingent on investors' expectations for future demand.[17] Present decisions depend on expected futures, and actual futures depend on present decisions. This is the challenge of endogenous uncertainty in economics.[18]

Climate change is a remarkable example of the complex interplay between long and short-run developments in todays world economy. The Framework Convention on Climate Change is part of today's international environmental diplomacy, and it fosters studies of how to develop technologies and products that could help reducing greenhouse gas emissions. These, in turn, are part of R&D efforts undertaken by today's governments and businesses. The possible disruptions of the global climate system that these measures are supposed to mitigate, however, are likely to reach their climax way after the year 2100 [22]. This is due both to the time horizon over which humankind is likely to use the carbon available in the earth crust and to the time constants involved in the climate system, especially its oceanic components.

Of course, some future demand is anticipated by *futures* markets operating in the present. But except for financial assets, futures markets exist only for a few goods and services and only for a very limited time horizon. In most cases, long-term decisions must rely on expectations that are not based on the interplay of futures markets, but on the "animal spirits" of investors [23]. For climate economics, this means that actual markets can hardly be expected to take care of climatic risks. There are no futures markets for land in Bangladesh in the year 2100 – and if there were, purchasing power disparities would give little weight to the interests of Bangladeshi people in the decision-making process.

The difference between short-run and long-run economic decisions raises two major questions with regard to the role of expectations for the sustainability transition:

a) How do economic agents form their expectations about environmental changes that may happen in the long-run?
b) How do such expectations influence long-run economic decisions?

As for the first question, we know at least four patterns of expectation formation that are relevant here. The first one is plain knowledge acquisition. In the case of climate change, scientific research can show that certain outcomes – say a sea level rise of 1m within 1 century – are possible as a consequence of human greenhouse gas emissions, while other events – say a sea level rise of 10 m within 10 years – are not. Usually, climate change research establishes that some event is possible or not, without attaching objective probabilities to it, although vague notions of "being likely" are often expressed by the experts from the relevant field.

In some cases, the relevant knowledge is a public good available to economic agents at no cost. Where information acquisition is costly, economic agents may try to acquire as much information as needed to take a decision that they consider satisfactory both in its expected outcome and in the reliability of this expectation. This is the second pattern: satisficing behavior along the lines of bounded rationality. The third pattern is Bayesian learning [24]. If some economic agent – say a multinational oil company – considers climate change as highly unlikely on the basis of the evidence available at some point in time, that agent may change her expectation as additional evidence – say about long-term temperature trends – becomes available. The fourth pattern is pure guessing. This lies at the heart of notions of subjective probability, but also of the state-preference approach pioneered by Arrow [25] and Debreu [26]. Just as human beings can prefer apples to oranges, they can prefer one uncertain situation to another one – even if they know nothing about relative frequencies. But while recent work by Becker [27] and others has begun to shed

[16] Suppose somebody sells a quantity of wheat today for whatever amount of money the market allows for. Now suppose there is a futures market for wheat and consider the quantity of tomorrow's wheat which that amount of money can buy today. Then, the difference between these two quantities of wheat divided by the initial quantity is the wheat own-rate of interest. There is no reason why it should be equal to the own-rate of interest of, say, bricks. Otherwise, no changes in relative prices would be possible and therefore no adjustment of production patterns to demand for future products. (The analysis of own-rates of interest goes back to Sraffa's critique of Hayek [19]).

[17] A model of this kind is proposed by Morishima [20].

[18] A promising approach to the problem of endogenous uncertainty has been proposed by Kurz [21].

some light on the formation of preferences, so far little is known about the formation of those subjective probabilities that enter Bayesian learning as priors.

As for the second question, it is far more intricate. The role of expectations for economic dynamics lies at the heart of some of the most important debates both in economic theory and policymaking. According to the efficient market hypothesis (EMH), at any moment in time current prices reflect all available information in the most accurate manner possible, taking into account different preferences and endowments in wealth.[19] Current prices here include spot prices for future contracts – today's spot price for wheat harvested one year in the future gives the expected value of the future price, discounted with today's rate of interest. EMH is based on the idea that arbitrage will eliminate imperfections in information processing by market participants.

We do not want to overemphasize the importance of EMH as such, rather we use it as a powerful way of addressing the difference between two temporal scales in economics. For policy purposes, EMH gives support to a general approach of *laissez-faire* and to general skepticism of discretionary – as opposed to rule-based – policies. In the case of climate policy, for example, economic agents should be given access to the best possible scientific evidence and enabled to work out its economic implications for themselves.

Two objections to EMH that are relevant here.[20] First, many real world markets are imperfect by the standards of the theory of competitive markets, and one may ask whether this jeopardizes the capability of economic agents to deal efficiently with the risks of climate change. The global oil market is clearly shaped by a few multinational corporations, none of which is faced with the horizontal demand function characteristic for firms operating under perfect competition. (Similar situations arise for other markets with key relevance for climate change). Bounded rationality provides ways to describe such markets without buying in to EMH. Under such descriptions, expectations are formed according to adaptive learning: economic agents observe current events and try to learn from the past. According to EMH, however, past prices provide no additional information to current prices when trying to forecast future price dynamics. Nevertheless, the fact that real oil prices are remarkably sticky since more than one hundred years is something one would not wish to ignore when studying climate policy. When oil prices underwent major shocks, these have been linked to large scale recessions, and even wars, until after a while they returned to their long-term level.

One answer to this experience has been provided by real business cycle theory, which argues that markets are efficient but that they take some time to work out the implications of exogenous shocks. This has been shown to be plausible even if economic agents do not form their expectations by adaptive learning, but if instead they are characterized by rational expectations.[21] The latter concept provides a formalized version of Hayek's [31] argument that no centralized authority can match the information processing capability of decentralized markets. Economic agents can know the structure of the economy at least as well as governments can. Accordingly, they can work out the implications of exogenous shocks for the system as a whole without any need for government assistance.

The second objection to EMH, which may turn out to be even more important for integrated assessments regarding the sustainability transition, is based on empirical evidence concerning stock markets. In stock markets, the volume of trading and the volatility of prices are much larger than reasonable applications of EMH suggest. A possible explanation combines the absence of futures markets with adaptive learning by heterogeneous agents to understand the imperfections of actual stock markets. While this is certainly an important line of research, a more comprehensive approach is possible thanks to recent research. The Debreu-Sonnenschein-Mantel theorem ([32], see also Kurz [21]) shows that theoretically sound general equilibrium models produce not one equilibrium, but a whole set – which may be finite, countable, or uncountable – of equilibria. Only extreme assumptions can guarantee uniqueness of equilibrium.

Clearly, this faces economic agents with a major coordination problem in equilibrium selection [33]. As Schelling [34] has shown, such problems may be solved by establishing some focal point of attention. They cannot be solved by utility maximization, however, because all relevant equilibria are Pareto optima in their own right. Even if endowed with rational expectations and a full suite of futures markets, therefore, economic agents would need some additional mechanism of expectation formation if they are to act at all. One such mechanism has been discussed under the label of "sunspot equilibria," meaning the focussing of expectations by some exogenous event without additional causal impact on the economy. And while nowadays sunspots are a highly implausible candidate for such focussing, expectations of global climate change may well become a plausible one. Two more mechanisms which may be relevant for the sustainability transition deserve our attention. The first is based the role of science in today's global society: Scientific knowledge claims may focus expectations of investors on certain technological trajectories long before the profitability of such trajectories can be assessed. While this mechanism relates to long-term investment, a completely different mechanism, namely price stickiness, helps economic agents to coordinate their expectations in the short run [35].

[19]The origins of EMH go back to Samuelson [28].

[20]A recent criticism of EMH relating both to the short and the long-run is to be found in Lo and MacKinlay [29].

[21]The idea of rational expectations was introduced by Lucas [30].

Summing up: expectations may be formed in a variety of ways, some of which are reasonably well understood. Formation of priors and/or state preferences, however, clearly need further research. Expectations may shape the economy in two ways. First, they are essential for the way the economy digests exogenous shocks. And second, they are essential to cope with situations of endogenous uncertainty, where no single equilibrium is given.

So far, economic work on expectations has been carried out mainly – but by no means only – in financial economics. Environmental economics has not yet taken advantage of this body of work. In particular, familiar models used in climate economics do not include representations of monetary phenomena. This is no big problem if one subscribes to EMH and real business cycle theory, but even then it is of course insufficient to discuss, say, the impact of carbon taxes on inflation or the role of the financial sector in shaping technical progress. It seems advisable, however, to develop models that would enable us to compare the EMH case with the one of adaptive expectations and the sunspot case.

In a first step, this would mean an effort to use findings and methods available from other domains of economic research. As the role of expectations for economic dynamics is by no means settled in contemporary economic theorizing, one might also expect the study of the sustainability transition to contribute to significant advances in general theory. Policy advice referring to global environmental change may be greatly improved by explicitly addressing the role of different time scales in economic decision-making.

5. CONCLUSION

Scaling issues in economics are not mainly about the up- and downscaling of models and the interpolation between discrete data points, important as these issues are in economics as elsewhere. The main issues concern deep changes in the laws and patterns that govern economic processes at different spatial, temporal and institutional scales.

Much further research is warranted to deal with these issues. What should be clear by now, however, is that the role of nation states will need a thorough reappraisal in view of the sustainability transition. Are markets to take care of decisions affecting the short-run future, and governments advised by scientists to take care of long-term decisions about energy systems, urban development, and the like? This would turn Hayek's [31] argument on its head: the most important decisions would not be taken by markets, but by governments. From the point of view of the global economy, however, nation states may be provider of club goods rather than public goods, and it is not clear whether in the long-run they will be the appropriate providers of the latter [36].

Do we need a complete set of futures markets ranging over the next centuries in order to deal with the challenge of the sustainability transition? Such markets would leave decisions over the future of humankind in the hands of that tiny fraction of humans which currently is in a position to take major investment decisions, and it would greatly amplify the risks of speculative bubbles on futures markets.

The thorny, if fascinating, issue of global governance calls for major institutional innovations. From an economic point of view, one may wonder whether political institutions are really the one and only kind of institutions to consider for this purpose. Perhaps, far-reaching innovations will take place in the realm of economic institutions, too.[22] The sustainability transition can hardly be engineered by some more or less intelligent central agency, but at the same time it cannot take place without new structures and processes of global management. Learning to deal with scaling issues in economics will be vital in order to meet the challenge of sustainability.

ACKNOWLEDGEMENTS

This paper owes much to careful comments by Tom Evans and to discussions in Harry's club, an informal gathering of economists which originated at the EFIEA workshop on Uncertainty, held in Baden, Austria, in July 1999. The Michael Otto Foundation for Environmental Protection provided financial support. The usual disclaimers apply.

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[22] In this respect, sustainability studies may have much to gain from the seminal analysis in Drucker [37].

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