Introduction

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Abstract: The central question about the impact of technical change concerns the extent to which new knowledge promotes innovation and sustainable development. We argue that this can be achieved only through the continuous diffusion of science and technology, which implies we improve our understanding of the conditions that have influenced globally integrated learning processes. Learning, in this context, considers inclusive and sustainable processes of knowledge creation and diffusion, in a way to impact the global economy, but following local roots and fostering the inclusive development of our society. Although much of the attention in recent literature has been focused on the complex relationships between scientific development and the economics of innovation, the analysis has been extended in order to adequately address emerging sustainability issues. It considers the human resource dimension and gained from several approaches that have recently shown the need to broaden the analysis of innovation systems to consider competence building.

This broad concept has motivated the work behind the present special issue, which was launched through two consecutive workshops organised during the International Conferences on Technology Policy and Innovation held in Kansai and in Monterey in the summers of 2002 and 2003, respectively (as described in http://in3.dem.ist.utl.pt/confpolicy/). The workshops brought together a range of experts to discuss environmental technology, policy and management in a context much influenced by the dynamics of change and a necessary balance between the creation and diffusion of knowledge. Thus, this special issue includes a set of extended and revised contributions that are largely grounded on empirical experiences of different national contexts. The aim of this introductory paper is to set the stage for these contributions, with an original contribution on possible views for emerging technology policies.

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1 Introduction: the evidence – the accelerated rate of technical change

The relationship between knowledge and economic development is increasingly the focus of research and policies aimed at ameliorating the standards of living around the world (Conceição and Heitor, 2005). This relationship includes the processes through which the creation, distribution and use of knowledge contribute to economic growth. Much of this new perspective is being driven by the perception that the growth in the stock of knowledge is unprecedented. The key point here is not only that there is rapid technological change, but that there seems to be an accelerating rate of technological progress. Fogel (1999) chooses to contrast the development of the plough, around 4000 B.C., with the development of flight, a constant ambition of the human spirit. It took 2000 years to diffuse the plough across Mediterranean shores, with little improvement, but only 66 years to go from the first aeroplane flight in 1903 to the point when a man could walk on the moon.

Ashby (2000) has also analysed how the importance of different materials (*i.e.*, metals, polymers, composites, ceramics) has changed with time, making use of the level of their relative usage by society over the centuries and showing, for example, that the use of metals increased until the 1960s, although their relative importance decreased at a fast rate when compared with any other change in the last 10 000 years.

It is also well known that, today, new knowledge and products are diffused far more quickly than before. The progress in information and communication technologies has allowed decreasing production costs, above all those associated with the diffusion and processing of information. This progress is well documented through the well-known Guilder and Moore laws, as discussed by Freeman and Louçã (2002). The law of George Guilder is associated with the explosion of bandwidth in terms of the quantity of data to be transmitted through a communication line. In the 1960s, a transatlantic cable could support about 168 conversations/minute, while today an optical fibre supports over 1.5 million conversations, reducing the cost of an international telephonic call from about three USD/minute to less than one centime/minute. On the other hand, Gordon Moore estimated in 1965 that microprocessor power would double every year, but revised that estimate in 1975 and suggested that the capacity would double every two years. Based on these estimates, Gates (1996) estimated that the current doubling rate occurs every 18 months.

In fact, the advent of digital technologies has captured the minds of businesspeople, policymakers and many academics. The computer, new telecommunications devices and, more recently, the internet are indeed powerful and impressive technologies. They are affecting people and firms in fundamental and permanent ways. Within this context, it is not surprising that many countries, regions and cities around the world are trying to catch the wave of the internet and digital technologies.

The fundamental question to be asked is that if computer-associated firms can benefit from IT technological advances, why should firms in other sectors not do the same? It may take more time for the benefits to reveal themselves statistically in other industries, but eventually a spillover to other industries is likely to arise. As discussed above, anecdotal evidence already suggests that digital technologies are gaining momentum in terms of their economic weight and in the changes they are driving in people and firm behaviour. According to some, the computer and its associated digital technologies are part of a regime transition, following the pioneering formulation of Freeman and Perez (1986). This hypothesis suggests that the emergence of a new radical technology requires a number of minor technological improvements, as well as institutional and social adjustments, to make its impact noted in the economy. In brief, the emergence of a radical technology requires time. Historical analyses proposed by David (1990), among others, show that previous important technological breakthroughs took decades to have a measurable economic effect. In his 1990 work, he focused on the substitution of electric motors for steam engines, and established a historical equivalence with the computer. David (2000) suggests that the same type of 'delaying' mechanism is at work today with digital technologies and the internet. There have been attempts to formalise these hypotheses, under the emerging field of the study of *general purpose technologies*. The collection of essays in Helpman (1998) provides a snapshot of this literature.

In summary, while much attention has been devoted to digital technologies, the association between information technologies and economic development (as measured in terms of productivity) remains ambiguous. Still, it is undeniable that the spread of the computer and the internet is profoundly changing the way people and firms behave and interact, with important consequences for policy and strategy. A more fundamental change is the increasing importance of knowledge for sustainable development. This feature of today's developed countries corresponds to the continuation of the trend of accelerating the importance of knowledge creation and diffusion throughout the century. Beyond digital technologies, other technological breakthroughs, in many areas from the life sciences to the many fields of engineering, are likely to occur.

To frame the complex context associated with the processes of technical change and their impact, the next section introduces the concept of the techno-economic paradigm, in order to explain the time and space of the processes of technical change. Then, in Section 3, we briefly address the need to better understand the conditions fostering the sustainable development of our societies. This leads us to approach, in Section 4, the need for policies fostering learning and the importance of knowledge diffusion. The final section introduces the papers included in this special issue.

2 The techno-economic paradigms approach: a review

The interaction between the emergence of new technologies and the larger economic and social patterns of behaviour can be understood, following Schumpeter, as a process of creative destruction. At a first approximation, this statement is obvious: new technologies disrupt and often replace older ones. At a higher level of analysis, the implications of new technologies are broader. The impact is often felt not only to be a substitution of older for new technologies, but to bring with it opportunities for new firms and difficulties for existing firms, the obsolescence of some occupations and shifts in the

structure of employment, and changes in the terms of trade between regions and countries. On the other hand, it is clear that not all advances in technology are disruptive to the point of creating substantial changes in economic and social conditions. In fact, most technological advances and innovations make their impact felt in a relatively smooth way, when analysed from a macro perspective.

One way to conceptualise the interaction between technological change and shifts in economic conditions, together with the process of sometimes-disruptive innovations, but most often the smooth adoption and diffusion of new technologies, is the idea of techno-economic paradigms. A techno-economic paradigm embodies a relatively stable cluster of core technologies, around which innovation and economic activity take place. The core technologies have a strong impact on the economy and society, being defined as core given their potential for generalisation and penetration across a wide number of products and processes, across all sectors of economic, and often human, activity.

Within a paradigm, the core technologies are virtually unchanged over time, but this does not mean that there is no economic and technological progress. On the contrary, these core technologies provide a positive heuristic that defines the knowledge and incentives for innovation and economic activity to occur. At the same time, this progress is inherently limited by the conditions set by the interaction of the core technologies with the dominant modes of economic activity, from the organisation of firms to the distribution of employment. Therefore, progress exists within a certain techno-economic paradigm, but occurs within a framework defined by a set of core technologies and modes of organising economic activity.

Thus, within a paradigm, innovation occurs as the core technologies become more and more pervasive and influence ever-wider realms of production and distribution. When a major technological advance occurs, disrupting the existing core technologies and modes of economic operation, a new techno-economic paradigm emerges. The displacement of the core technologies of the old paradigm creates a new wave of invention and innovation and is no longer tied to the previous paradigm's core technologies. The emergence of a new core technology requires, and creates the opportunity for, an entirely new set of small and incremental innovations that permit the widespread usage of the new core technologies. Thus, when a shift in techno-economic paradigm occurs, we have not only a 'substitution effect', but also an expansion of the creative frontier that allows the emergence of new technologies and enables, in the end, a shift to yet another techno-economic paradigm.

Additionally, beyond the technological and purely economic factors, the social and institutional frameworks that fit a certain techno-economic paradigm may not be adequate for a new one. Indeed, the process of emergence of a new techno-economic paradigm results from the interaction of the technological, economic, institutional and social spheres. Having just a new technology coming in may not have any effect if a set of changes in the other dimensions does not accompany the technological novelty. A certain set of institutions and social features may provide enough contexts for innovation within a certain paradigm; in other words, it is not necessarily needed to create institutions and social rules at the same pace that technological innovation progresses. But when there is a shift in techno-economic paradigm, a new institutional framework may be needed.

A number of authors, working together and independently, developed the theory of techno-economic paradigms, primarily Christopher Freeman and his coauthors. Often called a 'neo-Schumpeterian' approach, this perspective is articulated in Freeman *et al.*

(1982), Freeman and Perez (1986), Dosi (1996) and, more recently, McKnight *et al.* (2000), to cite a few representative examples. Freeman and his coauthors generalised the concept of Schumpeterian innovation to the national level, making an analogy between innovation at the firm level and a change in a techno-economic paradigm at the country level (Freeman and Soete, 1997).

This macroeconomic definition of innovation corresponds to what is, at the firm level, a radical innovation. Under this extreme there are milder types of innovation, like incremental innovations, which correspond, at the micro level, to improvements in existing products and processes. Freeman builds a similar hierarchy for his macro analysis of innovation, leading to a conceptual framework that has some similarity to the evolutionary perspective of Nelson and Winter (1982).

It is important to stress two important dimensions of the techno-economic paradigm theory: time and space. Time is indeed crucial, as we saw, since the process of technological change and its economic and social impact is seen as progress, more stable within a certain techno-economic paradigm, and very different across techno-economic paradigms, which differ over time. Space is equally important, since it is not clear that a certain techno-economic paradigm will not affect all the regions of the world similarly. Certainly there will be different rates of adoption of new core technologies when there is a paradigm shift, or even, within a paradigm, different ways in which specific innovations and modes of economic organisation develop in different countries and different regions. Some countries may originate or lead the development of a new techno-economic paradigm, and others may lag behind, or even stay closer to older paradigms than the new techno-economic paradigm.

An important idea joining the time and space dimensions of the techno-economic paradigm theory is that of technological trajectories within national innovation systems. The idea of trajectories in national innovation systems speaks of the fact that each country follows its own developmental path, within the general framework of the existing techno-economic paradigm, but also – and this is crucially important – influenced by the history and specific conditions of the local context.

This brings to the discussion the asymmetries in country performance, which, according to our interpretation advanced in earlier papers, can be seen as being dependent on what we could call with generality knowledge accumulation through 'learning' processes. Conceptually, the foundations for the relationship between learning and economic growth are well established in the literature, and stem from a combination of the pure neoclassical perspective of growth and the Schumpeterian view. Learning is reflected in improved skills in people and in the generation, diffusion and usage of new ideas. Likewise, organisational learning reflects social processes driven by collective cultures and appropriate management attitudes. The ability to continuously generate skills and ideas (which is to say, to accumulate knowledge through learning) is the ultimate driver of an economy's long-run prospects (Conceição and Heitor, 2005).

The fact that countries have different levels of income is clearly self-evident. Therefore, it is equally obvious that each country has followed its own trajectory, within the context of an existing techno-economic paradigm and the specific innovation system of the nation. We look here at some evidence of the translation of different paths in the economic performance of countries. But we begin with an interpretation of the major techno-economic paradigms, illustrated in Table 1.

While the paradigms presented results from one interpretation, they now serve to illustrate with some empirical evidence the features of techno-economic paradigms presented before. Let us consider, for example, the first techno-economic paradigm. This corresponds to the emergence of the Industrial Revolution, as mechanisation was increasingly incorporated in manufacturing, especially in some industries, such as textiles. However, the technologies that were well diffused and used within this paradigm presented some important limitations for the increase in the scale and output of productive activity. Most firms remained small and local. Process control was poor and hand-operated machines did not allow output of reliable quality. Naturally, advances in steam engine technologies and machinery were already taking place, but it took a long time before they were ready for fruition.

Table 1 Tentative sketch of major techno-economic paradigms

Approximate period	*Description*	*Key sectors*	*Economic organisation*
1770s to 1840s	Early mechanisation	Textiles, canals, turnpike roads	Individual entrepreneurs and small firms; local capital and individual wealth
1830s to 1890s	Steam power and railway	Steam engines, railway, world shipping	Small-firm competition, but emergence of large firms with unprecedented size; limited liability corporations and joint stock ownership
1880s to 1940s	Electrical and heavy engineering	Electrical engineering, chemical process industries, steel ships, heavy armaments	Giant firms, cartels, trusts; mergers and acquisitions; state regulation and enforcement of anti-trust; professional management teams
1930s to 1980s	Fordist mass production	Automobiles, aircraft, consumer durables, synthetic materials	Oligopolistic competition; emergence of multinational corporations; rise of foreign direct investment; vertical integration; technocratic management styles and approaches
1970s to …	Information and communication	Computers, software, telecommunications, digital technologies	Networks of large and small firms based increasingly on computer networks; wave of entrepreneurial activity associated with new technologies; strong regional clusters of innovative and entrepreneurial firms

Source: Adapted from Freeman and Soete (1997)

When these important technologies matured to the level that made their economic utilisation possible, they became the core technologies of the second techno-economic paradigm. The new techno-economic paradigm based on the steam engine and on machinery ameliorated some of the previous limitations, and created in itself the germ for new types of economic organisation, as the table details.

If we cross the techno-economic paradigms with geography, we then start joining together the ideas of technological trajectory and national innovation system. The first two techno-economic paradigms were led by Britain. In this context, the USA and Germany, for example, were 'latecomers'. Still, they became leaders in the third techno-economic paradigm, with Japan also leading in the fourth and the USA arguably retaining the lead alone in the fifth, although we will be looking at this claim in more detail below.

In conclusion, the techno-economic paradigms perspective provides a useful conceptual tool for framing a dynamic analysis of the evolution of innovation systems. This perspective highlights, as noted, the interdependence between space and time that leads to the path-dependent determination of the current innovative performance of countries. With this in mind, we now turn, first, to a historical analysis of innovation and science and technology policymaking, in general, and to a look at the Portuguese context, afterwards.

3 Beyond techno-economic paradigms: the need for inclusive development

Let us consider a virtually unanimously accepted statement: innovations, and especially technological innovations, have been the major drivers of the unprecedented improvement in the standards of living of developed countries since the Industrial Revolution. Kuznets (1966) named 'modern economic growth' the economic progress of developed countries from the outset of the Industrial Revolution. According to Landes (2003), it is only after the Industrial Revolution that technology has been systematically impacting on economic growth. Technological change drives industrial development, and thus having 'industrialisation' is a required condition for a country's growth to be driven by technology. In Kuznets's own words:

> "We may say that certainly since the second half of the nineteenth century, the major source of economic growth in the developed countries has been science-based technology – in the electrical, internal combustion, electronic, nuclear, and biological fields, among others."

If it is unquestionable that technological progress has driven the overall improvements in the standards of living across the globe, it is also clear that many countries and many people have been excluded from the benefits of new technology and innovations. Beyond technology, it is 'knowledge' (ideas and skilled and educated people) that is increasingly important for economic development. In developed countries incentives exist to reward and to stimulate the generation of new ideas and to promote investments in education and training. But we must question whether they are in place in developing countries. According to the United Nations (1998), 1.3 billion people in developing countries live on less than $1 a day, 32% of the population in transition economies on less than $4 a day and 11% in industrial countries on less than $14.4 a day. If the developing countries, on average, have much less income than developed countries, one still cannot overlook the fact that even within developed countries many people have been excluded from the process of development. Duncan (1999) provides a description of the deep and persistent poverty that plagues many communities in the USA, especially in the Appalachian and in the Mississippi delta. In fact, the situation is much worse than a mere asymmetry in the distribution of material assets, and thus is largely underestimated when measured only in terms of differences in income per capita.

This discussion frames the issue of the need to promote 'inclusive development', that is, of the need for a process of development that includes every citizen in any country, as a problem that goes beyond the creation of conditions to generate knowledge. Incentives to create knowledge exist, in fact, and though needing to be perfected and deepened, have worked rather well for the most part. The most important problem concerns the sharing and diffusion of knowledge. The mere fact that in the economics literature this 'diffusion'

process has largely been explained in terms of externalities and spillovers shows that the sharing process is largely an unintended consequence and, in fact, a disincentive for private agents to invest in knowledge creation. Thus the logic of government intervention, namely in terms of science and technology policies that tackle these market deficiencies, has been to provide incentives to enhance knowledge generation.

In our opinion, if the issue of inclusive development is indeed to be acknowledged as important, efforts should be channelled towards the understanding of the conditions for globally integrated learning processes. Learning, in this context, reflects the idea of sustainable knowledge creation and diffusion, and we contend that the challenge is to make this a feature not exclusive to a few countries but instead part of the entire global economy. This special issue intends to be a contribution to the effort of studying the conditions for inclusive development through globally integrated learning processes.

4 Conclusion: learning and the importance of knowledge diffusion

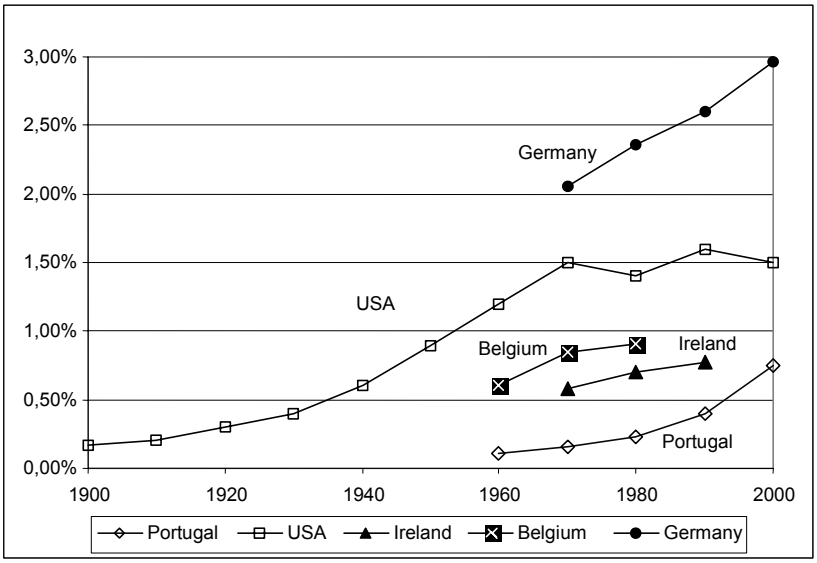
The challenges for policy to move towards inclusive development and wealth generation are really twofold. First, what can be done at the regional and national level to start and sustain learning networks and trajectories that can lead to wealth creation? Second, how can the overall global learning processes be made more inclusive, so that fewer countries are excluded, extending the reach of the learning networks globally?

As we emphasised in earlier papers, learning can occur in many shapes and forms, some of which are informal and other formal (Conceição and Heitor, 2005). The institutions and organisations that constitute the national and regional systems of science and technology attempt largely to formalise and accelerate the learning process for individuals, firms and nations. Thus, by looking at this particular set of organisations, their networks and institutions, we would be able to suggest routes for policy that can positively influence the conditions for inclusive development through learning.

It is clear from the literature that the welfare of individuals, organisations and countries is based, particularly since the first industrial revolution, on the creation, diffusion and use of technology. During the last decades of the 20th century, this reality was reflected in the trend in most developed economies of promoting investments in high technology, research and development, and in technical education, as well as investments in education and culture (Figure 1).

According to Romer (2000), the role of public policies in science and technology training is particularly critical to economic growth over the long run. These policies accounted for the rapid increase in the number of engineers and scientists in the USA from the postwar period to the 1970s. In fact, the study of the relationship between knowledge creation and economic development is an increasingly important component of research on public policies that seek to stimulate growth. It is legitimate to argue about changes to the traditional way of thinking about economic growth, and to question the role played in that process by the technical education and science and technology systems. In short, these reflections are based on a new conceptual approach to economic development, in that knowledge accumulation appears as a fundamental engine of the development process.

Figure 1 Percentage of graduated engineers in active population aged between 25 and 64 years old in a selected group of OECD countries



Source: Adapted from Conceição and Heitor (2005)

For many authors, the idea of knowledge-based economies is still more of a concept than a reality that can be objectively characterised. This characterisation has been based essentially on stylised facts, like the growing incorporation of knowledge in physical products, the increase in the value associated with ideas *vis-à-vis* material goods, and the high importance of services. Traditionally, economic growth has been explained as resulting from the growth of labour and capital factors, and of technological change. It is important, however, to rethink the way these factors occur in the process of economic development.

Regarding the contribution of labour, the evidence is that the quantitative increase in the population is insufficient to account for the verified economic growth. This is because the developed economies increasingly produce intangible factors, creating employment mainly in the service sector, where education and professional qualifications are requested. Thus, for growth and employment creation, it is crucial to increase human capital so that access to more and better skills, namely through education, can be promoted.

As far as the contribution of capital is concerned, the accumulation of intangible assets has gained importance *vis-à-vis* physical capital. Thus, the importance of knowledge does not only appear through the contribution of technological change, which has led to the need to rethink the traditional patterns of explaining economic growth. For instance, the new growth theories include many of these efforts, suggesting that knowledge accumulation can be understood as learning and is the most important factor to explain the process of economic development in the long run.

What does this discussion have to do with technical change and the role of technical education and of research in the economy? To introduce this question, it is important to consider, in the first place, the traditional perspective of economic growth, for which

growth results from the accumulation of the work and capital factors, as well as of technological change. The introduction of the technology factor, which is due to Solow (1956; 1957), proved to be essential for the empirical explanation of the measured growth levels. The simple accumulation of the work and capital factors has never been enough. But technology always appeared as being external to the economic process, an exogenous component, as mentioned in the specialised literature.

The perspective according to the new theories of economic growth is completely different. The accumulation of capital, or, in the new nomenclature, of objects, continues to be essential. But the only source of continued growth is knowledge: new ideas to produce new objects and to organise the existing objects in an increasingly efficient way, on one hand. On the other hand, new and improved skills allow the implementation of ideas and the use of objects. For example, Romer (1994) has a simple principle: new ideas and new and better skills, that is, more knowledge, are really responsible for productivity and efficiency gains, resulting in economic growth. As a matter of fact, mankind has been constrained since the beginning of civilisation by the natural resources and energy with which our planet was gifted. Human development results only from the knowledge that is generated and accumulated, allowing the rearrangement of these resources in an increasingly productive manner.

Thus, in the new growth theories, knowledge, in the first place, is not limited to technology, and, in the second place, is not exogenous. It corresponds, alternatively, to new ideas and skills, not only in the technological field, but also in the social, legal, political and administrative fields, among others.

If it is true that knowledge accumulation accounts for the largest contribution to growth, it is now important to briefly discuss how that accumulation happens. In other words, knowledge accumulation means to learn, not in the strict sense of an individual learning, but in a wider context, where one can speak about organisational, national and regional learning.

The formalisation of the economic development process in the new growth theories follows the model originally proposed by Arrow (1962). It is important to briefly focus on the analysis of Arrow since it contains the essence of the foundation of economic development as a learning process. Instead of following the orthodoxy at the time, which attributed the inexplicable growth component according to the accumulation of the work and capital factors to technological change, Arrow argued that the experience in capital use led to an increase in knowledge used in production. In a more prosaic way, Arrow formalised in a relatively simple model the idea that the workers of a company learn with the use of production means, increasing the company's productivity.

Therefore, learning, *i.e.*, knowledge accumulation, appears as the engine of efficiency increases, resulting in economic growth. It is interesting to notice that Arrow chose an informal way of learning, learning by doing, to support his thinking. In this model, knowledge is entirely accumulated under the form of skills. The contribution of the new theories of economic growth was, precisely, to extend this thinking to other learning types, as well as the accumulation of ideas, starting from the moment that Romer (1986) demonstrated the generality of Arrow's arguments.

Two other models of new theories have been pointing out the formal institutional mechanisms that exist in our society to accelerate the learning process, namely, education and research. The models that depend on education follow Lucas's (1988) seminal work, while Romer (1990) and Grossman and Helpman (1991) are the canonical references for the models that have research and innovation as an endogenous growth source.

Pasinetti (1981) articulated in a very clear way the idea that learning is the source of growth, having observed that, "Since man is able to learn, advancement occurs because the next society has always a better departure point than the previous."

In this context, Pasinetti considers that the human capacity to learn is the key factor for economic growth, a perspective that is the foundation for the new growth theories. Nevertheless, according to Pasinetti, the sources and growth mechanisms are different from those considered by the new theorists of economic growth.

Analysis shows that some of the more highly considered authors, who are linked to the new economic growth theories, analysed knowledge accumulation under the form of skills, education being a formal learning process. Additionally, models were also developed wherein the accumulation of ideas stems from the effort in research, another formal process of learning. In this context, two aspects should be pointed out.

Firstly, in the early 1990s the focus was on the study of the accumulation of ideas through R&D, a tendency that has been reinforced in recent works. There are at least two reasons for this. On one hand, the study of the informal learning process is more complex and less likely to be tested empirically. This leaves room for reflection about the accumulation of ideas through R&D, since studies on education's role have a considerable past, bearing in mind the theories on the human capital in the 1960s. On the other hand, a truly remarkable modern-day fact is the growing codification of knowledge, and the potential that the digital economy or the 'information society' reserves for us.

Secondly, there has been a recent interest in analysing the economic implications of the resulting learning processes of social interaction, mainly under the scope of the 'information society'. Actually, this aspect introduces a new vision for the education system, namely, regarding the radical change in magisterial teaching towards an announced learning, which is directly associated with continuous training (lifelong), and to the need to manage different demands and a multifaceted public. Additionally, the fact that informal processes of learning are being shared by a diversified spectrum of institutions makes it possible to open new perspectives to the science and technology system and to create and disseminate knowledge.

5 Introducing this special issue

This special issue integrates a set of new contributions addressing complementary aspects of relevance towards improved understanding of the process of technical change as driven by increased environmental awareness.

Ferrão and Nhambiu, in the following paper, discuss the use of an Economic Input-Output Life Cycle Assessment (EIO-LCA) framework, which makes use of official data provided by each European member state, under the National Accounts Matrix including Environmental Accounts (NAMEA), in order to enable the analysis of the environmental performance of economic sectors. Methodological extensions to this framework that enable the environmental assessment of processes and products are discussed, and future developments are forecasted on the basis of work in progress under this scientific area. The evolution of the contribution to the Portuguese GDP of the main economic sectors, between 1993 and 1995, was analysed, and the relevance of a life-cycle perspective can be correlated with the relative contribution of direct and

indirect contributions of the economic sectors to fulfil the total demand in the national economy. The analysis clearly demonstrates that indirect costs are very relevant for many of the sectors analysed. It is shown that if environmental impacts associated with the products or services in the economy were considered only on the basis of the contribution of the different sectors directly contributing to their fulfilment, ignoring the needs from the other sectors to fulfil the needs of those directly involved, it would result in major errors in environmental accounting, which would be miscalculated. The results obtained show that between 1993 and 1995 the Portuguese GDP increased by 10%, while the GHG emissions contributed to increase GWP by 0.6%. The combined results reflect an increase in the global environmental efficiency of the economy. However, there is clear evidence of different environmental performances across the main economic sectors within the Portuguese economy.

Junmo Kim, in the third paper, utilises the US Energy Information Administration data, which is the official energy statistics from the US government, on CO_2 emissions of 49 countries and other key statistics in time-series format and employs time-series-tuned cluster and discriminant analysis to extract determinants that have shaped the global pattern of CO_2 emissions from 1980 to 1998. The determinants feature how individual countries have developed growth patterns, as expressed in CO_2 emissions in the given time frame.

Outcomes from the research so far confirmed that is possible to distill a four-group structure of nations whose grouping was calculated on the basis of similarity of annual change patterns of CO_2 emissions. From the analysis, three roots or determinants were found, which are the annual movement of the US money supply, US deposit rate and petroleum consumption on the global scale. The data reveal that the US economy, especially its money supply, has had a meaningful impact on shaping the global economy as expressed in the CO_2 emissions pattern, which can be regarded as a mirror image of production activities. Secondary resource consumption patterns, like that of petroleum, also had its effect on shaping the economy, although its importance has been relatively milder.

Amaral *et al.*, in the fourth paper, discuss waste management on the basis of financial 'extended producer responsibility' and stipulate minimum reuse and recovery rates for the automobile industry. The authors argue that creating an economically robust recycling infrastructure involves a significant effort to develop systems and procedures that will have to meet requirements established by emerging End-of-Life Vehicle (ELV) directives. In particular, recent innovations in Automotive Shredder Residue (ASR) separation technologies and subsequent materials recycling are a candidate for constituting an alternative strategy to classic component-dismantling procedures. Two main strategies to reach the recycling targets established by EU directives and especially to solve the problems caused by the light fraction of the ASR currently going to landfill were analysed, namely: a) reducing the amount of ASR by more intensive dismantling of ELV components, under financial incentives for pre-established parts or materials used in the vehicles; and b) upgrading the technologies available for processing the light and heavy fraction of the ASR by developing separation technologies and finding recycling possibilities for the products gained from the separation. It is clear that nowadays only metal recycling has proved to be economically feasible and, as a consequence, the significant value of plastics content suggests the need to build a more effective plastics recycling infrastructure, which is the emphasis on both strategies previously defined.

Borger and Kruglianskas, in the fifth paper, discuss an empirical study on the impact of adopting corporate social responsibility strategies by Brazilian enterprises. The authors argue that actions oriented towards enterprise social responsibility are complex, because organisations are composed of people with many different positions in the organisational hierarchy and diverging beliefs, values and interests, and of many processes which require coordination, as well as social, cultural, economical and institutional atmospheres. This generates expectations and behaviour patterns that are different for the individuals, entities and social agents that interact with the enterprises.

Conceição *et al.*, in the final paper, build on previous research on the contemporary role of the university and argue that it must respond to changes in the world that challenge its well-established pedagogical and epistemological traditions or face loss of institutional respect and power. Concerns over the rapid pace of exogenous socio/economic change and the increasingly unsustainable state of the world raise questions about the efficacy of the positivist, discipline-based model for learning, research and teaching, and simultaneously charge universities with the important task of diffusing the concept of sustainability. An alternate model of reflexive learning in practice (living) is introduced as a potential model for the building of the 'sustainable' university. In particular, this model explicitly addresses the development of norms as part of the learning process and ties this to a concept of sustainability in which responsibility is central. The analysis is based on sample initiatives in progress and shows that the importance of learning sustainability through the experience of living requires radical changes in the university. Interdisciplinary research and curricula are critical, but face well-established resistance to change. Integrative concepts such as industrial ecology can guide the design of new institutional structures.

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