The Importance of Adopting an Alternative Approach to Neo-classical Economics : The Case of Climate Policy

Full text

Presented to the Association of Heterodox Economics (AHE) by Kevin Marechal, PhD Student at the Centre for Economic and Social Studies on the Environment at the Free University of Brussels (CESSE-ULB), in view of a presentation at the AHE 8th annual conference « Economics, Pluralism, and the Social Sciences» scheduled to take place in London from 14th to 16th July 2006

1. Introduction

Nowadays, economics has become an unavoidable discipline in the field of policy making. From a tool supporting decision-making processes, it is now often used as the unique science of decision-making. Its intertwining with policy-making and the prominence of its jargon (starring words like competition, efficiency, etc.) seem deeply anchored in modern societies. This is largely due to the fact that economics is able to offer a theoretical framework that allows for a policy assessment based on metric values, which is highly appreciated by decision-makers.

Paradoxically (or maybe not), despite its political popularity, traditional economics[1] is also being challenged as never before (see Gowdy and Erickson, 2005 for a brief overview of recent sources of criticism). Its relevance has been strongly questioned by scholars from several fields - both from a theoretical and an empirical standpoints. Indeed, its criticisms are no longer targeted solely towards the theoretical inconsistencies of the principle of maximisation at the aggregate level, which governs traditional welfare theory (from the early critics of Scitovsky, 1941 right after Kaldor, 1939 and Hicks, 1939 were published to those formulated more recently in Suzumura, 1999 without forgetting the important work of two Nobel-prize winners, Samuelson, 1950 and Sen, 1977), but a substantial body of empirical evidence is also being gathered to demonstrate that the *Homo Oeconomicus* paradigm is, to say the least, highly disputable. Yet, the neo-classical paradigm still remains the dominant standard among economists and their audience (van den Bergh J. and J. Gowdy, 2003).

Climate policy is no exception to that trend. From the very beginning of international talks on this issue, up until the most recent discussions on a post-2012 international framework, economic arguments have turned out to be crucial elements of the analysis that shapes policy responses to the climate threat[2]. And strict Walrasian computable general equilibrium (CGE) models – the primary tool of traditional economics - clearly dominate most of climate-

[1] We use the word "traditional" ("modern", "mainstream" or "orthodox" could also be used) to avoid the problems arising from the somewhat ambiguous use of the term "neoclassical", as shown in Colander, 2000. By traditional economics, we refer to the Walrasian model of welfare economics which can be defined as the theoretical synthesis of the Marshallian approach with marginal production theory and the rigorous precision of mechanical mathematics. It can be dated back to the second half of the 19th century with the work of economists like Alchian, Friedman, etc.

[2] Among the most important decisions based on a pure economic argument is undoubtedly the US withdrawal from the Kyoto Protocol, based on the argument that it was "fatally flawed" (http://www.whitehouse.gov/news/releases/2001/06/20010611-2.html).

related economic analysis (Laitner J., S. DeCanio and I. Peters, 2000)[3]. The problem is that, despite severe criticisms and a proven non neutrality, the systematic use of traditional economics is not much discussed, so that its influence on policy-making still goes unhindered[4] (which is, somewhat asymmetrically, not the case of the scientific basis underlying climate policy-making, which is still hotly debated despite the large consensus it generates among experts).

This paper is structured as follows. In the following section, we present a brief overview of the underlying historical factors on which traditional economics is built. Then, in section 3 we show the concrete impacts of the traditional paradigm on the way crucial aspects of climate analysis are dealt with, with a strong focus on the question of technological change. In section 4, we provide an alternative approach and sketch some of its policy implications. Section 5 then concludes.

2. The mechanical foundations of traditional economics

Traditional economics is often considered to be the counterpart of neo-Darwinism in biology (i.e. the integration of Darwin's theory with the genetics of Mendel). This is mainly due to the obvious influence that Spencer's interpretation of Darwin's theory (i.e. the "survival of the fittest") has had on many leading neo-classical economists (Hodgson, 1993) For example Friedman (1953, p. 22) relies strongly on the natural selection analogy to elaborate his argument in favour of the neoclassical model and its predictive power.

However, following the analysis of Dopfer (2005), it seems more appropriate to envisage traditional economics as Newtonian considering that the traditional framework turned mechanical mathematics into the new Mecca of economists[5] - a choice obviously made to the detriment of biology, the other potential Mecca of economics (Hodgson,1993b; Foster, 1997; Witt 2004). Indeed, Alfred Marshall had shown that it was possible to reconcile the objective and subjective approaches to value by using biological analogies but subsequent economists (for instance, Marshall's influential follower Pigou) did not pursue his example and turned instead to physics for inspiration (Corning, 1996).

According to the traditional view, "maximisation" can be considered as the Newtonian invariant law of economics[6]. Thus, exogenous forces (i.e. external shocks) only can trigger a structural change and push the system out of equilibrium – an equilibrium which is then re-established through competition and market forces (Foster, 1997). This model is said to be universally deterministic (Dopfer, 2005). It also reduces individuals to their mechanical properties, and Prigogine (2005) shows that this can be attributed to the well-anchored philosophical view of Descartes. Indeed, Descartes' concept of "dualism", which distinguishes between the physical and the spiritual world, has led to the idea that only physical phenomena are worthy of scientific enquiry and theoretical construction because, unlike the "soft" side of reality, there are visible, comprehensible and measurable (see also Chen, 2005).

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[3] The focus on flexible mechanisms and the creation of an international emission trading system are the clear results of having adopted the framework of traditional economics.
[4] The range of models used in Weyant. et al. (1999) provides a clear example of the omnipresence of CGE models in economic analyses of the climate issue.
[5] Foster (1997, p. 432) argues convincingly that both Spencer's neo-Darwinian synthesis and neo-classical economics (i.e. traditional) are Newtonian.
[6] Similarly, Smith's "invisible hand" is the invariant law of the Classical model.

The axiom of perfect rationality of the Homo Oeconomicus, which constitutes the foundation of traditional economics, rests on that notion of "dualism", or separable entities. However, the development of modern neuroscience renders that view somewhat obsolete, because the brain can no longer be considered as the ultimate "black box" it was formerly thought to be (Camerer et al, 2005).

As Damasio (1995, 2000), shows, the presence of cortical interconnectivity in the human brain (in a "communication" zone[7]) means not only that we are able to exert a control over our automatic functions and instincts (located in the archecortex), but also that emotions, moods and other feelings can influence our conscious behaviour (governed by the neocortex). This implies that economic decisions are partly guided by feelings, and thus emotionally coloured[8]. Emotions are a vital part of our mental architecture (Muramatsu and Hanoch, 2005). As Dopfer (2005 p. 25) nicely puts it, this brain configuration provides the human being with "intelligent emotions and emotional intelligence".

It is worth noting that a lot of experimental studies in the realm of "neuroeconomics" (i.e. experimental studies expanded to include measures of biological and neural processes involved during economic activities) support this view (Camerer and Lowenstein, 2004). It also fits the information gathered by an abundant empirical literature dealing with the actual behaviour of economic agents (see, for instance, Fehr E. et S. Gächter, 2000; Henrich et al., 2001) as well as related ethnographic data (Richerson P. and R. Boyd, 2000). More specifically, those studies strike a fatal blow to the traditional paradigm's assumptions of exogenous and self-regarding preferences (Bowles and. Gintis, 2004), by revealing the existence of some degree of altruism (under the form of "strong reciprocity", as proposed in Gintis, 2000) and group–level influence (most particularly through culture[9]).

This empirical evidence as well as other theoretical inconsistencies (for example, concerning the transitivity of preferences, see Tversky, 1969) puts into question the relevance of traditional economics, and with it, the current policy-making approach based on the traditional economic framework.

3. The impact of analysing climate policy using traditional economics

Although traditional welfare economics has been said by Nobel-prize winner Joseph Stiglitz to be "of little relevance to modern industrial economies (Stiglitz 1994, p. 28)", it still lays the foundations of the economic guidance given to policy-makers on a variety of critical issues (Gowdy, 2004). For instance, Arrow et al. (2004) base their environmental policy recommendations on traditional welfare economics and on the idea of perfect substitutability between manufactured capital and natural capital. In addition, as preferences are assumed exogenous, the main issue is to "get the price right". The market outcome can thus be considered as the optimal allocation of resources, and consumers are left with the choice between environmental degradation or economic losses

The problem with environmental amenities – like climate – is that they are non-market "goods" for which there is no price. In addition to that, the climate issue is even more tricky to handle, because it is global in scope (even though its presumed impacts are geographically differentiated) and has implications that are long-term (which implies dealing with intergenerational equity) and potentially irreversible. Any framework inherently favouring the

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[7] This interaction takes place through a complex thalamo-cortical link (more precisely located between the thalamus and the paleocortex) which allows all parts of the entire cortex to communicate (Crabbe, 1998).
[8] On the importance of emotions in economic activities, see, for example, Lowenstein (2000).
[9] For a good introduction to the debate on the importance of culture see Henrich (2004).

short term and assuming that damages can always be financially compensated is of little use in that context (Maréchal and Choquette 2006).
To illustrate the impact of analysing the climate issue through the paradigm of traditional economics, we can examine the crucial notion of abatement costs (i.e. the costs of reducing greenhouse gas emissions)[10]. In a trivial way, abatement costs depend on both the reduction effort (difference between the target and a *business as usual* scenario) and the reduction potential.

3.1. Reduction potential

In climate-related literature, much research has been devoted to the analysis of a "no regret" emission reduction potential, which triggered an extensive debate among economists (see IPCC, 1996a, chapter 8 and 9 for an overview). An emission reduction potential is said to be "no regret" when the costs of implementing a measure are more than offset by the direct or indirect benefits (i.e. not including climate-related benefits) it generates based on traditional financial criteria.

The most obvious non-climate benefits are those arising from reduced energy bills following, for instance, the use of more energy-efficient appliances. Many bottom-up studies have shed light on the existence of such "no regret" investments in the field of energy efficiency, and showed that their magnitude can be substantial (see Tellus Institute, 1998; Interlaboratory Working Group, 2000; Krause, 1996). The fact that these investments are not realized spontaneously is often called the "efficiency gap", and it is partly explained by the existence of market "failures" and "barriers" (see Jaffe et al, 1994; Brown, 2001)[11]. Yet, a review of 52 case studies by Laitner and Finman (2000) has shown that the non-energy benefits of certain measures could be of the same order of magnitude as their energy benefits. This enhances the credibility of the "Porter hypothesis", which argues that investments undertaken to reduce environmental impacts may trigger productivity gains (Porter and van der Linde, 1995). This seems to have been the case for British Petroleum. Between 1998 and 2001, BP reduced its emissions by 18%, while gaining 650 millions $ of net present value (BP, 2003, p. 23) – a gain that occurred because the bulk of the emission reductions came from the elimination of leaks and waste (Browne, 2004).

It thus seems to be possible to reduce GHG emissions and reap economic benefits at the same time. This has been proven to be possible in cities and companies (Climate Group, 2004), in US steel firms (Worell et al, 2003) and on a macroeconomic scale (The Allen Consulting Group, 2004).

It is not surprising that the existence of a "no regret" potential was first highlighted by bottom-up engineering approaches, as it is incompatible with traditional economic theory. Indeed, according to the traditional paradigm, if such a profitable potential did exist, economic agents (optimising machines) would spontaneously undertake the necessary investments to capture it. Faced with overwhelming evidence on the "efficiency gap", traditional economists resorted to the existence of hidden costs (mostly transaction costs) to rescue the Homo Oeconomicus paradigm (see, for instance, Sutherland, 1991). However, such costs do indeed exist, but bottom-up studies have shown that they do not quite offset the benefits from identified profitable energy-efficient investments (see Brown, 2001 for a survey of such studies). More

[10] This notion has indeed played a dominant role in international talks and has formed the basis on which many countries have shaped their position on climate issues.
[11] Following the definitions in Jaffe et al (1994), it is important to note that only market "failures" (misplaced incentives, , distortionary taxes, etc.) are amenable to intervention (if policies that are low-cost and feasible exist) in the traditional economics framework.

specifically, transactions costs can be drastically reduced when programs are put in place so that synergy effect arise (Levine and Sonneblick, 1994). EU decision-makers understood this possibility quite well and launched labelling systems for electric appliances like refrigerators. In some EU region, financial support (in the form of subsidies) is also given. Taken together, these measures allow economic agents to overcome two major obstacles hindering energy efficiency, namely the lack of information and the lack of access to capital.

3.2. Reduction effort

A reduction effort – such as that imposed by the Kyoto Protocol on the developed countries that have ratified it – is defined as the difference between an emission target and a *business-as-usual* scenario. By convention, reduction efforts within the framework of the Kyoto Protocol are estimated with reference to 2010, the central year of the first commitment period (from 2008 to 2012). Obviously[12], the only unknown data is the BaU scenario which is supposed to give an estimated answer to the question "where will we be in 2010 if we do not do anything?". A careful analysis of these scenarios shows that the way technological progress is modelled is of crucial importance for the results (Maréchal et al, 2002).

This fact is not more surprising than the "no regret" debate, because in traditional modelling (i.e. *à la Solow-Swann*[13]) technological change enters the production function as an exogenous variable (Mulder et al, 1999). In energy-related studies, this "manna from heaven" type of modelling takes the form of the AEEI (Autonomous Energy Efficiency Improvement) factor like in the famous DICE/RICE model (see Nordhaus, 1994). Based on that kind of framework, it is then straightforward to recommend a "laisser-faire" approach to decision-makers in climate policy and wait until technical progress brings solutions (Gowdy, 2004). Thus, what seems to be the result of an economic modelling exercise is in fact already implied by the assumptions of the model (DeCanio, 1997).

This is confirmed by a recent retrospective study which analyses previous energy forecasts made in the US and shows that they systematically overestimate energy consumption (Sanstad et al, 2003). This tendency is largely explained by an inappropriate way of modelling energy efficiency improvements (see also Craig et al. 2002). Varilek and Marenzi (2001) also come to similar conclusions when they compare forecasted and effective prices on the US SO_2 emissions trading market.

3.3. The economic impact of reducing GHG emissions

The fact that "no regret" measures are not taken into account and that technological change is modelled as an exogenous parameter inevitably gives a pessimistic view on the possibility to tackle the climate issue at an affordable cost: traditional analysis both fails to integrate profitable energy investments, and underestimates the penetration of energy efficiency (Laitner et al, 2000).

[12] This will only be true by the end of 2006 when emissions inventories are consolidated and reference levels (with respect to which reduction objectives are calculated) are known for sure.
[13] During the 1980's with the work Paul Romer and Robert Lucas, traditional modelling of technological change (TC) was enlarged to include human capital (see Mulder et al, 2001). This was a first step towards modelling TC as an endogenous variable in response to the critics like those formulated in Nelson and Winter (1982). More recently Aghion and Howitt (1998) provided a Schumpeterian type of traditional modelling but it still fundamentally differs from the approach we will adopt in this paper (see section 4.2.). For a good overview of the history of the different "induced" TC modelling - within and outside the traditional paradigm - see Ruttan (2002).

Thus, given that the main assumptions of traditional economics are strongly questioned, it seems interesting to investigate the impact that an alternative economic framework (more in line with empirical data) would have on climate policy in general, and on the modelling of technological change in particular. This is even more interesting considering that technological evolution has historically had a tumultuous relationship with environmental problems, being alternately their cause and their remedy (see Gray, 1989 for an overview of this ambiguous relationship).

4. The impact of adopting an alternative framework

Considering the criticisms formulated against traditional economics, it seems clearly necessary to reconcile the theoretical characterisation of the economic agent with the recent empirical findings, while defining a framework that allows for the integration of such a characterisation. This calls for the opening of economics to insights from other disciplines such as psychology, anthropology and biology.

Setting an entire alternative paradigm to traditional economics is beyond the scope of this paper. Nevertheless, we make the premise that an evolutionary-inspired line of thought, applied to a specific issue such as technological change modelling in energy-related issues could provide an insightful alternative.

4.1. A brief discussion of our evolutionary view

As long ago as the turn of the nineteenth century, Veblen (1898) wondered "Why economics is not a evolutionary science". Today, more than 20 years after the publication of the seminal article of Nelson and Winter (1982), evolutionary economics is a well established branch of economics (Arena and Lazaric, 2003). Yet evolutionary economics is far from constituting a stable alternative paradigm, because internal debates still agitate those who adhere to that school of thought (Arena and Lazaric, 2003). In the following paragraphs, we intend to define our own approach by clarifying our position with respect to the main fundamental issues in evolutionary economics.

One of the main debates relates to the usefulness of resorting to biological analogies, and more particularly the concept of natural selection (for recent papers on that issue see Cordes, 2004; Vanberg, 2004; Hodgson and Knudsen, 2004, 2005 ; Buenstorf, 2005). This led to an intense discussion on the "Darwinian vs Lamarckian" nature of evolution or, to put it differently, on the purposefulness of selection (Hodgson, 2001, 2002; Hodgson and Knudsen 2005).

Even though some authors have claimed that teleological (i.e. purposeful) selection has been acknowledged and integrated into the neo-Darwinian framework (see Corning, 1996), most economists (among them two Nobel prize winners, Simon 1981 and Hayek 1998) assert that economic evolution, like cultural evolution, is Lamarckian.

We could agree with such a claim, since what has been "darwinised" is the notion of selection with an *objective* purpose, whereas economic evolution could arguably be seen as involving *subjective* purposefulness. The important concept here is the possibility for teleological systems to create their own goals, or, in other words, the consciousness of the pursued finality (Miquel, 2000) – a possibility that is not allowed for in the neo-Darwinian framework.

The problem is that, perhaps due to the lack of a clear definition of the Lamarckian hypothesis in biology (Wilkins, 2001), most economists' claimed adhesion to lamarckianism is no longer obvious when its conceptualisation is carefully assessed (Foster, 1997; Knudsen, 2000; Hodgson, 2001). For Hodgson (2003, p. 376), this is also the case of the founding work of Nelson and Winter, 1982. This naturally leads him and other authors (Vanberg, 2004) to call for "Universal Darwinism[14]", as they believe that lamarckianism can be seen as a complement to Darwinism, as long as we do not deal with biological[15]. As Hodgson (2002), p. 270, puts it, along with domain-specific "auxiliary explanations" Darwinian principles are applicable to a wide range of phenomena. But to some authors, those "auxiliary" explanations are so important that they render the concept of "universal Darwinism" a non-neutral paradigm (Witt, 2004; Buenstorf, 2005). For example, purposefulness of economic action allows for a feedback between variation and selection and thus makes these two basic Darwinian principles interdependent (Cordes, 2004) – an interdependence that is not possible in molecular biology (see, for instance, Mayr, 1991).

The approach we adopt in this paper analyses economic evolution in line with the vision adopted in Witt (2003, p. 15) and labelled the "continuity hypothesis", hence acknowledging the relevance of Darwinism but insisting on the non-neutrality of "universal darwinism" as an epistemological heuristics. This framework rests upon the idea that darwinian-type of selection has provided human beings with evolved cognitive and learning skills (Tomasello, 1999) that constitute the basis for other forms of evolution to take place (Witt, 2003). These other forms of evolution (cultural, economic, etc.) are different from biological evolution in that, for instance, they allow for multiple parentage and transmission across lineage (Cordes, 2004). But above all, economic evolution takes place on a shorter time scale. All together, this makes it irrelevant to assess economic change through Darwinian lenses. It is also important to underline that the "continuity hypothesis" does fit empirical data on cultural evolution, which highlights the fact that biological evolution ceased to exert a systematic influence on the human genome - which is not much different from what it was 20000 years ago (Mayr, 2001, p. 261 ; Witt, 2003, p. 16 ; see also the anthropological data in the work of Boyd and Richerson, 1980 and the literature on cultural evolution like, for instance, Durham, 1991 and Henrich, 2004).

However, this does not preclude in any way the relevance of using other biological metaphors for inspiration; for instance, "exaptation" which refers to characteristics that have been selected for a purpose other than the one it is now used for, or for no purpose at all (Gould and Vbra, 1982).

What is important in our perspective is to underline the need to analyse economic evolution as a process of continuous, double (downward and upward) and interactive causation (van den Bergh and Gowdy, 2003; Corning, 2003; see also the "Micro-meso-macro" approach in Dopfer, Foster and Potts, 2005). That is to say, what exists today is not the result of the sole selection at the individual level. More precisely, some socially-acquired characteristics of human beings (like "Strong reciprocity" see supra) are better explained by group level analysis (Henrich, 2004).

In sum, our view of economic evolution is in line with both the "continuity hypothesis" and the "double causation" process. Following Gintis (2004), it can be illustrated by the above-

[14] First coined by Dawkins (1993) and then used by Hodgson (2002) and Hodgson and Knudsen (2004).
[15] Hodgson (2003), p. 360 considers Darwin himself as a Lamarckian so that both theories are no longer seen as mutually exclusive.

mentioned "Strong reciprocity" concept, which is nothing else than an "exaptation" arising from the biologically-evolved human capacity to internalise norms[16].

4.2. Technological change through evolutionary lenses

To define what we consider to be an evolutionary view of technological change (TC), we start from two elements. First, we follow Foster (1997, p. 433) and identify the lack of formal historical connection as a major drawback of many evolutionary analyses – which illustrates the risk of non-neutrality inherent in "Universal Darwinism", as natural selection is a time-reversible process and thus ahistorical. This inevitably guides us towards what could be called the "David and Arthur theory" (according to Dosi, 1997), which underlines the historically-contingent nature of economic change (see David, 1985 and Arthur, 1989).

Secondly, we agree with Mulder at al. (1999) that the added value of an evolutionary approach of TC, even compared to the most recent traditional analysis based on endogenous modelling of TC, is that TC is "contextualised", which is highlighted through a systemic vision of technologies as "interrelated" (see Veblen, 1915, p. 130).

In that context, our approach to technological change can de described as a synthesis of the work of David and Arthur, with an evolutionary framework in a systemic perspective. As mentioned in Dosi (1997, p 1539), the two approaches are highly compatible, and their synthesis is implicit in many recent works (Faber et al, 2005; Carillo-Hermosilla, 2005 ; Rammel, and van den Bergh, 2003 ; Unruh, 2000, 2002).

Within that framework, it is more appropriate to analyse technologies as belonging to "technological systems" (see Hughues 1983). Following Unruh (2000, p. 819), technological systems are defined as "inter-related components connected in a network or infrastructure that includes physical, social and informational elements". For example, the automobile transport system is composed of cars, roads, traffic signs, garages, etc.

If we push the systemic logic one step further, we see that technologies are not only linked to other technologies, but are also interrelated with the cultural and institutional aspects of their environment (see the example of the railway system in Kindleberger, 1964 or, the more general concept in Freeman and Perez, 1988). In this case, we talk about *Techno-Institutional Complexes* (Unruh, 2000) or, more common in the literature, *Technological Regimes* (Kemp, 1994).

This characterisation of technological systems composed of multiple interrelated elements sheds light on the potential inertia of such systems - an element that could not be revealed by analyses focusing on isolated technologies. In turn, this potential inertia invites us to investigate the historical conditions that lead to the emergence of a technological regime. This is why the notion of technological lock-in, pioneered by the work of David (1985) and Arthur (1989), has been the subject of a growing interest from scholars in different fields (Perkins, 2003). Recently, this concept has been applied in various studies that deal with environmental issues (see Faber et al, 2005; Carillo-Hermosilla, 2005 ; Rammel, and van den Bergh, 2003 ; Unruh, 2000, 2002 ; Kline, 2001 ; van den Bergh and Gowdy, 2000).

The notion of lock-in is linked to (and could be considered as a result of) the concept of path-dependence (Arthur 1983 ; David, 1985), which refers to the fact that technological systems follow specific trajectories that it is difficult and costly to change. As shown in Arthur (1989),

[16] Norms (or conformist transmission, see Henrich, 2004) are an adaptation to informational constraints.

these trajectories depend on historical circumstances, timing and strategy as much as optimality (i.e. the focus of traditional economics). That is to say, the presence of increasing returns to adoption (i.e. positive feedback that increase the attractiveness of a given technology when it is more and more adopted) can potentially lead to market domination (see Arthur, 1989, 1990, and 1994 and David, 1985)[17]. This mechanism is similar to a snowball, in the sense that a given technology which, for whatever reason, obtains an initial lead will eventually exclude other competitors as its early advantage is amplified through time because of increasing returns to adoption. Thus according to this process, and contrarily to what traditional economics says, the same distribution of technology and homogenous preferences of users could lead to different technological structures, depending on how things happen in the beginning (Economides, 1996).

Lock-in literature usually identifies four classes of increasing returns (Arthur, 1994). The first two classes – namely "scale economies" and "learning economies" – are well documented and commonly used by economists who have rested on them to build "learning curves" (Unruh 2000 ; Perkins, 2003). The impact of these two classes of economies is increased by a third type of increasing returns, namely "adaptive expectations", which refer to a reduced level of uncertainty as both users and producers become more confident about the technology's general quality (Arthur, 1991).

Finally, the last class of increasing returns to adoption is known as "network externalities" (see the pioneer work of Frankel, 1955 based on the concept of "interrelatedness" in Veblen, 1915 and, for more recent formalisations, Katz and Shapiro, 1985, 1986 and Farrell and Saloner, 1986). It is the one most commonly associated with the lock-in literature, and clearly results from the adoption of a systemic approach to technology. According to Katz and Shapiro (1985, p. 424), positive network externalities refer to the benefits that a user derives from a technology when the number of other users increases. They arise because physical and informational networks become more valuable as they grow in size, as it is obviously the case of hardware or phone networks, for example (Katz and Shapiro, 1985 ; Unruh, 2000).

The importance of network externalities is enhanced in our evolutionary framework, as they are thought to operate on technological systems that consist not only of multiple interrelated technologies and their supporting infrastructures, but also of technical, informational, economic and institutional relationships that enable them to work together (Perkins, 2003). This can be illustrated with the case of the automobile, whose expansion required parallel developments in supporting industries (steel, glass, etc.), infrastructures (service station, roads, etc.), academic research and lobbies (see the work of Flink, 1970 and 1988).

In addition, the codified standards that are use co-ordinate such technological regimes can also become a major source of lock-in (Unruh, 2000).This picture is even reinforced by the fact that, as highlighted by the notion of *technological paradigm* in Dosi (1982)[18], there is also a form of lock-in of ideas, which are shaped by the cognitive frame of actors and therefore determines exploration frontiers (see also Dosi et al, 2005). This reduced scope of investigation could explain why, as underlined in Mulder et al (1999, p. 6), most of technological change consists in incremental improvements rather than radical breakthroughs.

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[17] Arthur's theory of self-reinforcing mechanisms can be compared to the famous "Polya-urn" process (see Arthur et al, 1987, p. 295).
[18] That is inspired by the "scientific paradigm" of Kuhn, 1970.

From our evolutionary perspective, the last two centuries can be described as a succession of three dominant *technological regimes* (TR) : from 1800 to 1870, the dominant TR was composed of steam, iron and canals; then over the 1850-1940 period it was progressively replaced with coal, railways, steel and industrial electrification; and this last cluster has in turn been shifted to a TR made of oil, roads, plastics and mass electrification between 1920 and 2000 (see Grübler, 1998).

If it can be said that the existence of such clusters has long been acknowledged by economists (Perkins, 2003), the idea that the aforementioned lock-in process can lead to the dominance of an inferior design is highly disputed. This suggestion has first been made in David (1985) using the example of the QWERTY keyboards - an example sometimes considered to be the "Founding Myth" of path-dependence literature, as mentioned in Ruttan (1997, p. 1523). Indeed, the QWERTY keyboard is said to have been locked-in through the above-described process, to the detriment of superior keyboard designs (i.e. the Dvorak keyboard).

Because of its acquired status in the literature, the alleged superiority of QWERTY has been strongly disputed, most notably by Liebowitz and Margolis (1990), (1994) and (1995) who called it a "Fable". Their critics of the second most popular story, the "Betamax vs VHS" case (Arthur, 1990), were even more vehement, as they claimed that it was thanks to a real advantage (i.e. its longer playing time) that VHS came to dominate the market (Liebowitz and Margolis, 1994, p. 148). It is beyond the scope of this paper to present the details of the controversy over this symbolic case, but a brief look at the well-documented study performed in Cusumano et al (1992) would tend to contradict this version and give credit to Arthur's version[19].

Still, this controversy underlines the main problem with the "lock-in of inferior designs" hypothesis: the difficulty of empirically proving the superiority of "locked-out" alternatives (Cowan and Foray, 1999 talk about the counterfactual threat). For instance, when confronted with the idea that the gas-powered internal combustion engine might not be the best design (Arthur, 1989, p. 127), Liebowitz and Margolis (1994), p. 148 only oppose that they find this claim "difficult to take seriously". However, in line with Mokyr (1990), p. 191 or Unruh (2000), p. 821, existing studies again clearly show that Arthur's claim is at least worth analysing (our claim is based on a proper analysis of various papers: Arthur, 1989; Kirch, 1994 ; Cowan and Hulten, 1996 ; Foray, 1997 ; Rosenberg and Mowery, 1998 ; Foreman-Peck, 2000, 2001).

The case of the emergence of the light water reactor in nuclear plants, as explained in Cowan (1990), provides a more solid empirical example of the lock-in of an inferior design[20]. Even more solid yet is the evidence gathered in Scott (2001), which describes the lock-in of the British railway system into a small wagon systems. To us, all these examples[21] seem to make a case important enough to further investigate the lock-in process and identify some insights it could bring for policy-making.

4.3. The common background of the various "lock-in" stories

In all the aforementioned cases of suspected lock-in of inferior designs, we may distinguish two different periods in the lock-in process (Foray, 1997, p. 740). The initial period, whose duration may vary, exhibits very low increasing returns to adoption and thus reflects

[19] As the Betamax's playing had been extended well before the crucial arrival of the pre-recorded tape (see Cusumano et al, 1992).
[20] Interestingly this example is not even mentioned in Liebowitz (1994) and (1995).
[21] See also the "Battle of the current" case in Hughes (1983) and David and Bunn (1988).

preferences[22], which may be deliberate or not. This first period also varies in terms of the number of decisional events involved before a distribution of choices can be observed. In the nuclear example of Cowan (1990), there was one such event, whereas in the battle of the motors (Cowan and Hulten, 1996) or in battle of the videotape recorders (Cusumano et al, 1992), a succession of events was involved.

Then, the second period of the "lock-in" process starts with the appearance of dynamic complementarities, that is, positive feedback which are introduced in the system and tend to amplify the initial distribution of choices (see Foray, 1997, p. 740). These can take the form of complementary goods, like pre-recorded tapes in the VCR case (Cusumano et al, 1992); technical interrelatedness as in the case of the automobile (Flink, 1988); or the triggering of events, like those car races in France that undoubtedly had an impact on the selection of the gas-powered internal combustion engine (Foreman-Peck, 2001).

In line with the work of Veblen (1915), p. 130, complementarities are also important in that they provide an explanation for the persistence of obsolete intentions, as in the QWERTY case, whose design originated from the need to hinder typing speed to avoid type-bar clashes - a need that is no longer relevant to computers keyboards (Foray, 1997, p. 745. Interrelatedness generates an analytical bias known as the "profit gap" (see Frankel, 1955, p. 306), which helps explain the persistence of locked-in technologies like small wagons, even though they were substantially less profitable, as shown in Scott (2001), 371). Technological lock-in can even persist without increasing returns if other elements are in place (Balmann et al, 1996).

The bulk of lock-in stories that can be found in the literature also highlights the relevance of adopting a systemic approach to technology, as they all demonstrate how essential it is to take into account the unavoidable interactions that exist between related technologies, as well the role played by related institutions, whether public or private. In fact, taking technological systems into consideration makes it difficult to circumvent historical contingencies, as their importance turns out to be fundamental (see Carlsson, 1997). A detailed analysis of four different technological systems in Sweden shows that, though these four systems were very different in terms of economic success, evolution trajectory, etc., in all cases their evolution and configuration could not be rightly understood without analysing initial conditions and path-dependence (Carlsson, 1997, p. 796).

What we also see is that such a systemic reasoning has often been lacking in the decision-making process of crucial economic actors. This can be illustrated by the non-anticipated exponential growth of the sales and rentals of pre-recorded tapes in the VCR story (see Cusumano, 1992). Most of the time, deliberate choices cannot be qualified as "irrational", even in terms of financial profitability, but rather *systemically myopic* (or *systemically* "boundedly rational", to use the term coined by Herbert Simon). David (2000), p. 14, adds that even Thomas Edison's business strategy in the "Battle of the currents" – and especially its withdrawal from the flourishing electricity supply market - failed to correctly take into account the systemic aspects of his decision, even though it was driven by rational economic considerations (see also Rosenberg, 1982, p. 60).

It is obviously rather complex, if not nearly impossible, for an individual decision-maker to forecast all the complementary development to his technology, and to make decisions that are optimal for the whole system built around it. For instance, it would not have been easy to foresee the explosion of the American pre-recorded tape market, as market surveys

[22] It could be argued that these preferences are already historically determined.

indicated that only 8% percent of VCR owners found this product to be important (Klopfenstein, 1985 quoted in Cusumano, et al, 1992).

The analysis of railway gauges performed in Puffert (2002) is interesting because it adds one element – a spatial dimension - to the "lock-in of inferior designs" debate, and sheds a complementary light on the type of processes involved. It is also a very insightful analysis to deal with the dilemma of "standardisation vs diversity" (to which we will come back in section 4.4.). Puffert (2002), p. 285 provides convincing evidence for the existence of an initial period during which the "lock-in" process – including the making of path-dependent choices and the occurrence of positive feedback mechanisms - is clearly at play. However this study also shows that, even if the process never completely breaks free of early contingencies, in later stages the dynamics of choices are based on a rather systematic rationalisation (Puffert, 2002, p. 291) - which we could even call "systemic" rationalisation, as those later stages are driven by a quest for improved co-ordination and facilitated compatibility of neighbouring networks. The contrasted examples of the Netherlands and Spain (which does not use the "stephenson" gauge) provided in Puffert (2002), p. 285 underline the role played by conversion costs, which could also serve, for instance, to explain the persistence of the British system of standard weight and measures in the US (see Unruh, 2000, p. 822-823).

In the example of the Stephenson gauge, however, the historically-produced inefficiency does not really come from a wrong choice of dominant design - the "Stephenson" gauge is considered to be close to the optimal size - but rather stems from the persistence of other, non-compatible systems. The spatial dimension thus provides a complement to the model in Arthur (1989), as it allows for the lock-in of a dominant design (concept coined by Abernathy and Utterback, 1978) in parallel with the persistence of various small systems that are geographically spread out.

A modelling exercise performed in Jonard and Yildizoglu (1998) shows that diversity can be sustained even in the context of increasing returns to adoption. It all depends on the importance of "spatially localised learning" with respect to "network externalities" (Jonard and Yildizoglu, 1998, p. 47). Small "network externalities" can be a source of diversity (Jonard and Yildizoglu, 1998, p. 49). Therefore, lock-in can only arise if network externalities are strong enough. As mentioned by David (2000), p. 3, this shows that empirical enquiries remain necessary in order to determine what proportion of economic change can be understood more adequately through the approach adopted in this paper.

Yet, the most interesting result of the modelling exercise is that the biggest inefficiency comes from a reduction in technological progress when "lock-in" effects dominate as, in this case, the technological space is not fully explored (Yildizoglu, 1998, p. 47). That is in line with the aforementioned concept of "technological paradigm", by Dosi (1982).

4.4. Policy recommendations

The importance of historical contingencies, coupled with the impossibility of foreseeing future developments, is not without implications for public policies dealing with technological progress, including those related to climate change. As emphasised in David (2000), p. 14, this does not imply that governments should pick up the winners instead of letting markets decide – a choice that would involve a risk of locking-in a "dead-end" technology, as highlighted in Sanden (2004), p. 327-328. On the contrary, as mentioned in Foray (1997), p. 748, public authorities should pursue the objective of securing a good balance between diversity and standardisation, knowing that the gains from each are variable in time (see also

David and Rothwell, 1996). As Foray (1997), p. 748 puts it, a technology could emerge too early, or it could become too deeply entrenched.

Wisdom would thus require governments to delay their commitment to an inextricable future, in order to allow for the availability of sufficient information on any given option (David, 2000). In other words, governments should act to maintain a diverse range of technological options open (Berkhout, 2002, p. 3). For instance, in the "Battle of the motors", US engineers were able to switch from electric to gas-powered vehicles because they "did not put all the eggs in one basket, nor were they irrevocably committed to any particular technology" (Foreman-Peck, 1996, p. 9) - which allowed them to deal with conversion costs that were not as prohibitive as they were in the case of the Spanish railway tracks (see Puffert, 2002).

Furthermore, if we acknowledge that we are locked into an undesirable trajectory (as climate analysts could argue it to be the case of our economies that strongly rely on the use of exhaustible fossil fuels[23]), then it follows that we must find ways to unlock out of it (see Unruh, 2002). After all such shifts have happened in the past (see Berkhout, 2002, p. 3 and the above-mentioned three major technological regimes of history from Grübler, 1998).

Of course, unlocking ourselves from an undesirable trajectory is not a task that can easily be undertaken, because it is difficult to identify the solution that would yield the best outcome. We must also bear in mind the risk inherent to what has been called the "paradox of entrenchment" – that is, the need to create the conditions for the lock-in of a desired new technology to overcome the lock-in of an incumbent one (Walker, 2000). Unruh (2002), p. 323 adds that this risk increases when action is delayed, which implies that extreme measures must be implemented quickly. The new locked-in technology might then prevent superior technologies or designs to develop, as could be the case of solar energy technology, where crystalline silicon photovoltaics are possibly locking-out thin-film photovoltaics (Menanteau, 2000).

In any case, when defining their position in the face of several competing technologies, public governments should bear in mind the need to manage the risk of committing to inextricable trajectories, but they should also promote the type of measures that have been proven successful in overcoming lock-in situations (see the set of necessary conditions in Windrum, 1999, p. 31 and the key aspects indentified for regime shifts in Mulder et al, 1999, p. 9). This invites us to go one step further than the model of Arthur (1989), and to depart from its example of a competition between contemporaneous technologies (Windrum, 1999, p. 6). What is needed is a technological succession (Windrum and Birchenhall, 2005).

The example of the gas-turbine shown in details in Islas (1997) is very interesting as it illustrates both the need to create niches (i.e. a limited space where new technologies can mature[24]) and the possibility of overcoming lock-in with hybrid technologies. In that example, niches (namely aeronautics and peak power plants) allowed gas turbine technology to improve through a process of increasing returns to adoption (Islas, 1997, p. 63). Then the emergence of gas turbines into the bigger electrical base market occurred through the hybridisation between the incumbent steam turbines and auxiliary gas turbines – the latter finally becoming the main component (Islas, 1997, p. 64).

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[23] See Unruh (2000) or Arentsen et al, (2002)

[24] When there is a protection (whether public or not) a niche is said to be technological. If not, it is called a market niche (Mulder et al, 1999, p. 11). For instance, internet was developed within a technological niche whereas railways grew within a market niche (Windrum and Birchenhall, 2005, p. 125).

Based on this information and in line with Rosenberg (1982), a substantial body of literature focuses on "strategic niche management" (see Kemp, 1994 and Schot et al, 1994) in order to identify the key aspects that must be promoted for niches to be successful – a concern that arises because capturing a niche does not automatically lead to subsequent wider diffusion (see the example of the electric car in Mulder et al, 1999, p; 15). As mentioned in Unruh (2002), p; 322, niches are an attractive policy target since incumbent producers do not fiercely defend them, removing some of the resistance towards new entrants.

5. Conclusions

Our analysis shows that adopting an evolutionary approach to study technological progress could substantially alter the policies recommended by economic analysis, away from the current focus on the sole notion of efficiency[25]. Particularly, the lock-in process makes it unlikely that traditional cost-efficient measures (such as carbon taxation or tradable emission rights) aimed at internalising external costs will be sufficient to bring about the required radical change in the field of energy, because they fail to address structural barriers (del Rio and Unruh, 2006, p. 14). Climate policy should instead create conditions enabling the use of the cumulative and self-reinforcing character of technological change highlighted by evolutionary analyses (Mulder et al, 1999).

Adopting an evolutionary approach would also give a different picture of the challenge ahead than traditional analyses tend to do. For instance, Castelnuovo and Galeotti (2002), section 5, show that abatement costs are reduced by a factor of 3 or 5 when technological progress is modelled in a structurally endogenous way with respect to the outcome obtained using the same model but with exogenous modelling of technological change. Thus, as claimed by Grubb et al (2006, p. 19), the absence of endogenous technological change can bias policy assessment.

It thus appears that, in order to deal with climate change in an appropriate way, traditional economics must adapt.

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[25] An evolutionary perspective requires to also concentrate on the efficacy of interactions (Dopfer, 2005) or functional compatibilities (Windrum, 1999).

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