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ON THE FACES AND PHASES OF ECO-INNOVATION - ON THE DYNAMICS OF THE GREENING OF THE ECONOMY

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Abstract:
Green Growth and Climate mitigation have rapidly come to present one of the main grand societal challenges expected to have pervasive impacts on the global economy. However, theoretical and empirical insights into the greening of the economy are poor. Standard neoclassical economic research has failed to realize that markets are going green . But also evolutionary economics has neglected to address the role of environmental issues on economic evolution.
The novel concept of eco-innovation is increasingly connected to green growth, but is in need of further clarification. This paper suggests that the concept of eco-innovation could represent the evolutionary economic analysis of the greening of industry and the economy. The paper seeks to contribute to the development of evolutionary eco-innovation theory starting with a fundamental discussion on defining eco-innovation.
Hitherto eco-technologies or eco-innovations have been defined in technical terms. This paper suggests interpreting eco-innovation in economic terms. Eco-innovation is defined as innovations that attract green rents on the market. Hence the concept of eco-innovation reflects innovative changes in the economic system measuring the degree to which environmental issues are becoming integrated into the economic process.
Following this definition the eco-innovation concept is inherently linked to green competitiveness and the greening of the economy. The greening of markets should be seen as a specific historic phase and part of a

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– on the Dynamics of the Greening of the Economy

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Abstract

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The novel concept of “eco-innovation” is increasingly connected to green growth, but is in need of further clarification. This paper suggests that the concept of eco-innovation could represent the evolutionary economic approach to the analysis of the greening of industry and the economy. The paper seeks to contribute to the development of evolutionary eco-innovation theory starting with a fundamental discussion on defining eco-innovation.

Hitherto eco-technologies or eco-innovations have been defined in technical terms. This paper suggests interpreting eco-innovation in economic terms. *Eco-innovation is defined as innovations that attract green rents on the market.* Hence the concept of eco-innovation reflects innovative changes in the economic system measuring *the degree to which environmental issues are becoming integrated into the economic process.*

Following this definition the eco-innovation concept is inherently linked to green competitiveness and the greening of the economy. The greening of markets should be seen as a specific historic phase and part of a larger techno-economic paradigm change towards a “green learning economy”. The paper identifies five phases in the greening of markets and discusses the implications these have for eco-innovation dynamics.

Keywords: Eco-innovation, green growth, green markets, industrial dynamics, evolutionary economics, evolutionary capabilities, techno-economic paradigm change

Introduction

Green Growth and Climate mitigation have the last few years rapidly come to present one of the main grand societal challenges expected to have pervasive impacts on the global economy. However, theoretical and empirical insights into the greening of the economy are currently poor. Only 4-5

years ago the environmental agenda had quite a different lower standing, and the expectations as to its impact on economic development were moderate if not negative. Standard neoclassical economic research has failed to realize that markets have been going ”green”. But also evolutionary economics and the wider field of industrial dynamics has largely neglected addressing the role of environmental issues on economic evolution.

Eco-innovation is a novel fuzzy concept used by different disciplines and in need of further clarification both theoretically and methodologically. Analytically, the eco-innovation concept unifies environmental and economic goals in emphasizing green competitiveness as a core driver for environmental improvement; in relation to policy, it seeks to forward greater synergy between environmental and innovation policy. Eco-innovation policy represents a very immature policy area emerging slowly around the turn of the millennium but it is gaining a surpricing rapid global momentum these last 1-3 years, none the least at the level of international institutions such as EU, OECD and UN (EUROPEAN COMMISSION 2003, Kemp and Andersen, 2004; COM 2006, UNESCAP, 2007, OECD 2009a).

This paper suggests that the concept of eco-innovation could represent the evolutionary economic approach to the analysis of the greening of industry and the economy. The paper seeks to contribute to the development of evolutionary eco-innovation theory starting with a fundamental discussion on defining eco-innovation.

Hitherto eco-technologies or eco-innovations have been defined in technical terms. This paper suggests interpreting eco-innovation in economic terms. Eco-innovation from the suggested perspective is defined as *innovations that attract green rents on the market.* Following this definition the eco-innovation concept is inherently linked to the greening of markets and green competitiveness. Eco-innovation then is a measure of *the degree to which environmental issues are becoming integrated into the economic process.* The greening of markets should be seen as a specific historic phase and part of a larger techno-economic paradigm change towards a “green learning economy”. The paper identifies five phases in the greening of markets and discusses the implications these have for eco-innovation dynamics.

Research into eco-innovation is so far fairly limited. See though e.g. Fussler and James 1996, Andersen, 1999, 2002, 2006, 2008a, 2008, 20009a, 2009b, Andersen and Foxon, 2009, Fukasako 1999, WBCSD 2000, Rennings 2000, 2003, Hübner et al. 2000; Markusson, 2001, OECD 2005, Kemp 2000; Kemp and Andersen 2004; Foxon 2005, 2007, van den Bergh et al., 2006, 2007; Kemp and Paerson 2007; Reid and Miedzinski, 2008, Carrillo-Hermosilla et al. 2009, OECD 2009b). Much of this research has hitherto had a strong focus on policy issues and effects, while little attention has been paid to the innovation dynamics involved. We know hence currently very little both theoretically and empirically on eco-innovation dynamics and the overall greening of the economy.

This paper seeks to remedy this in providing a basic theoretical discussion on defining and understanding eco-innovation. While eco-technologies usually are defined in technical terms this paper suggests to interpret eco-innovation in economic terms. While neoclassical economic theory has dominated the environmental agenda the paper argues that the concept of eco-innovation may best be understood from an evolutionary economic theories hitherto very little applied in the environmental area. Basically the paper seeks to apply a more dynamic representation of the economic process in developing eco-innovation hence economic evolution. Using innovation cycle, innovation systems and techno-economic paradigm literature the paper identifies five phases in the greening of markets characterized by different eco-innovation dynamics.

The arguments in this paper are quite fundamental and should be supplemented by more particular studies of eco-innovation dynamics.

The chapter is structured as follows. Section 2 shortly defines and discusses the concept of eco-innovation from an industrial dynamics perspective. Section 3 examines eco-innovation dynamics and the greening of markets. Section 4 concludes and identifies areas for further research.

2. Understanding eco-innovation

This section seeks to come up with key insights and definitions on eco-innovation. The starting point is that it matters highly how we understand the economic process for how we understand eco-innovation. The main argument is that the concept of eco-innovation is important because, as defined here, it intersects environmental degradation with innovation and dynamic market processes.

Fundamentally “eco-technologies”, now superseded by the concept of “eco-innovations”, are technologies or services which remedy environmental problems. Understanding eco-innovation then entails understanding the changing relationship between society and nature and the attempts to develop novel solutions to deal with man-made environmental degradation. Traditionally, the framing of eco-technologies has been defined by neoclassical (“orthodox”) environmental economics. From this approach, environmental problems are seen as market failures deriving from negative externalities from production. Orthodox environmental economics thus centres on getting the prices right under consideration of social welfare. This entails calculations of the costs of polluting and the associated compensation that must be paid as well as the costs of not polluting (e.g. Baumol and Oates, 1988; Pearce et al 1989; Pearce and Turner, 1990, Birk Mortensen, 1991). Behind this argumentation lies an idealized market representation where rational, utilitarian agents in perfect competition are preoccupied with short run allocative questions leading to equilibrium. Time is reversible and agents have no history. This market representation

has dominated environmental analyses, -policymaking and -business strategies for 60 years and still influences strongly on the environmental and climate agenda (Andersen and Foxon, 2009).

This line of thinking has, however, some serious shortcomings in relation to understanding eco-innovation dynamics. Their dominating framing has been to see the environment as a burden to companies associated with production and administrative costs, and environmental policy as the only means to forcing companies to take on these extra costs. As a result, competitiveness and greening have been seen as strong opposites and the greening of markets has only slowly been realized. This notion has not only penetrated policymaking but has also been widely shared by companies which severely has hampered a shift from reactive towards proactive environmental strategies in companies (Andersen, 2002, Kemp and Andersen, 2004, Kemp, Andersen and Butter, 2004, Andersen and Foxon 2009). In this way the environmental area is a good example of the strong influence social scientific theories may have on societal development, none the least economic theory which gain much attention via the powerful economic ministries.

Evolutionary economic theory, within the wider industrial dynamic approach, forwards a very different dynamic perspective on the market which opens up for the possibility that markets can go green. Basic assumptions are that the economic process is subject to change, rationality is bounded, information is lacking and markets are hence inherently imperfect. In such dynamic markets, the ability to innovative and learn is seen as central to competitiveness, hence the emphasis on the knowledge economy or learning economy from this line of thinking (e.g. Lundvall 2002, 2005, OECD 2000). Variety, selection, cumulativeness, retention and routines are seen as central features of the economic process which are subject to time and space dependencies, (Schumpter, 1912/1961, Nelson and Winter, 1982, Dosi, 1982).

From this perspective innovative changes in the economic system may occur (Schumpeter 191219/61). However, issues of the role of negative externalities for economic evolution have only been dealt with very limited from this perspective. A few perspectives have been given: The externality problems, including environmental externalities, are treated as dynamic (Kemp and Soete,1992, Rennings 2000). The phenomena to which the "externality" tag is applied are not given but are related to particular historical and institutional contexts rather than definitive once-and-for-all categorizations. Nelson and Winter clarifies the externality problem from an evolutionary economic perspective:

"The canonical "externality" problem of evolutionary theory is the generation by new technologies of benefits and costs that old institutional structures ignore….There is no reason to believe that the lines between what society wants to leave private and what society wants to make public will remain constant over time. Whereas orthodoxy stresses achieving op-

timal provision of goods that by their nature are public, the evolutionary approach focuses on the changing circumstances that call for collective-choice machinery" (Nelson and Winter, 1982, pp.368-369).

The environmental problems are a good example of an area where the need for and the nature of public intervention has changed considerably over time, particularly the last 25-60 years. This line of thinking sees environmental problems as an aspect of economic change. With economic and technological development new environmental externalities will continuously be created and new institutional and organizational structures need to be developed to deal with these. The well-established "innovation systems" theory within evolutionary economics has only recently been applied to the environmental area and mainly for policy discussions, but it could provide an appropriate framework for capturing these systemic features of the eco-innovation process (Andersen 2009). The essence of innovation systems thinking is to view the economy as resulting from co-evolutionary processes of change in science, technology, organizations and institutions (see e.g. Freeman, 1987; Freeman, 1995; Lundvall, 1988, 1992 (ed.), 1999, 2005; Johnson, 1992; Nelson, 1993; Metcalf, 1995; Edquist, (ed.) 1997, Perez, 2000, OECD 2000, 2001a, 2001b, 2005; Freeman and Loucã, 2001, European Commission 2003, 2006; Fagerberg et al. 2008). The recognition of the importance of well-functioning institutional structures for a high innovative performance and economic development within this frame makes it the more remarkably that the externality discussion generally, and not the least environmental degradation, as mentioned has received little attention until now within this line of thinking (see though e.g. Hübner et al 2000, Kemp and Andersen, 2004, Foxon et al., 2005b, Foxon and Kemp, 2007; Andersen 2008a, 2009, Andersen and Foxon 2009 for some mainly policy oriented discussions from this perspective).

Analytically, the frame may highlight how new eco-innovations co-evolves with (demanding) changes in the economic organization on the market and institution formation within and surrounding the market as the market goes greener (see also Andersen, 2009). The evolutionary economic perspective, then, opens up for the possibility that environmental issues can be internalised into the economic process, i.e. a greening of markets, though this entails a major transformation process of the economy. As such the area illustrates important features of modern economies which to a still larger degree depend on well-functioning government structures for their overall competitiveness and functionality (Lundvall, 2005, OECD, 2005, 2009). This is none the least the case in the environmental area as we shall return to. Environmental problems are not a market failure, but rather an integrated part of the changing imperfections of the market (Andersen, 1999, 2002). Not being able to deal adequately with environmental problems is due to system failures in given national and regional innovation systems (Foxon, 2008, Andersen and Foxon,

2009). In the section on the greening of markets these aspects will be addressed more fully.

While the innovation system frame seems an adequate frame to capture eco-innovation dynamics because of its broad and very institutions oriented perspective on the innovation process, it has some limitations too. The analysis in the area tend so far to focus more on how innovation systems perform (benchmarking) than how they form (Andersen 2008, 2009).

The evolutionary capability approach may be helpful for the understanding of the micro-processes involved for central parts of the innovation system transition processes, although currently the two lines of research are little coupled. The evolutionary capabilities theory focuses on the firm-market dichotomy and alternative modes of economic coordination in dynamic markets where information is lacking and in flux. Analyses focus on investigating the relationship between the organisation of labour and knowledge (e.g. Penrose, 1959, Richardson, 1972, Teece, 1986, 1988, 1989, 2000, , Teece and Pisano, 1994, Dosi and Marengo, 1994, Loasby, 1996; Langlois 1992, 2003). There is little attention to the role of government intervention for this economic coordination. This approach puts more emphasis on firm agency and hence on strategizing and economic organization than pure evolutionary economic approaches to innovation.

None the less, the framework is helpful for the understanding of the high interfirm coordination costs involved when markets and innovation systems are undergoing rapid or major change as is the case in the greening of the economy. There are “dynamic transaction costs” when existing market-supporting institutions are inadequate to the needs of a new technology or profit opportunity (Langlois, 1992, 2003). As markets are given time and scope they catch up and the transaction costs sink (Langlois, 2003). The transaction costs discussion is essential for the understanding of the central interfirm dynamics of the greening of markets, which is highly dependent on the evolution of market-supporting institutions (Andersen, 1999, 2002, Andersen and Foxon, 2009). Integrating the evolutionary capabilities perspective in understanding eco-innovation dynamics, attention is brought to changes in the way learning and production is organized across different firms.

Below we will dig into more specific definitions of eco-innovation.

Defining eco-innovation

Eco-innovation is a novel, very complex and as yet fuzzy concept in need of theoretical and empirical clarification. Sharp and operational definitions are lacking and statistical data are poor. There is raising political interest in the in developing better classifications and indicators on eco-innovation none the least at EU and OECD levels (see EU COM 2004; Andersen, 2006; Kemp and Pearson, 2007; OECD 2009a, 2009b). Recent work in the area has brought more clarification, but still divergencies exist

(see Kemp and Arundel, 1998, Kuhndt et al., 2002a, 2002b, Arundel, Kemp and Parto 2004, Horbach (ed.) 2005, Andersen, 2006, Kemp and Pearson, 2007, OECD, 2009b; Carillo-Hermosilla et al. 2009). What is still lacking in the literature is linking up the given definitions and categories for eco-innovation to a theoretical discussion, none the least to gain deeper insights into the consequences of differences in framings and taxonomies for the eco-innovation dynamics involved.

"Eco-technologies" has to a very high degree been defined by policy agendas, illustrating the central role policy measures traditionally has had for the development of these technologies. As the environmental policy agenda has changed over time so has the notion of eco-innovation. With a still more preventive and integrated policy approach to environmental issues the focus has changed from environmental technologies/End-of Pipe to cleaner production processes, cleaner products to the broader eco-innovation or, even more widely used, clean-tech. Lately, low-carbon or climate technologies are added to the list of concepts.

This paper will not go into a very detailed discussion of specific taxonomies of eco-innovation categories. For the point of the more fundamental discussion on eco-innovation dynamics and the greening of markets in this paper, we will stick to two main eco-innovation categories:

A. Pollution- and resource handling technologies and services.
B. All technologies, products and services, which are more environmentally benign than their relevant alternatives

These two main categories are well consolidated in the literature and in accordance with the EU definition of environmental technologies (EU Com, 2004).

From these two eco-innovation categories it is apparent that eco-innovation is difficult not only to define but also to address because of the complexity but even more the relativity of the subject. This goes particularly for the category B eco-innovations which are a lot more complex and fluid. Greening is a moving target; innovations which are considered green today may be outrun by greener alternatives sooner or later (Andersen and Kemp 2004, Andersen, 2006, 2008b; Kemp and Pearson, 2007).

It is here suggested that the concept of eco-innovation differs qualitatively from the other green technology concepts in its economic orientation, i.e. taking the innovation part of the concept seriously. It should in other words be defined in economic rather than in technical or politological terms. The innovation concept is by now widely used and often abused treated as synonymous with transition. But from an innovation economic perspective it is defined more narrowly as novelty which leads to value creation on the market (OECD, 1997). Hence eco-innovations must be defined as green novelty which leads to value creation on the market. Another way of expressing this is that *eco-innovations are innovations which are*

able to attract green rents on the market (see also Andersen, 1999, 2002, 2006, 2008a, 2008b). They (appear to) reduce net environmental impacts while creating value on the market. Following this definition the eco-innovation concept is inherently linked to the greening of markets and green competitiveness. It is not decisive how green an innovation is but to what degree the environmental parameter has become a selection parameter on the market. Eco-innovation then is a measure of *the degree to which environmental issues are becoming integrated into the economic process.* Following this definition the concept intersects climate mitigation and environmental degradation with innovation and economic performance, more specifically dynamic market processes. The eco-innovation trend hence reflects a major innovative change in economic evolution.

The eco-innovations may, as other innovations, be technical, organizational or marketing innovations as long as they improve the "green competitiveness" of a company (Kemp and Andersen 2004, Andersen, 2006, 2008b). Hence the eco-innovation concept is more inclusive than earlier definitions of environmental technologies which typically have had a mainly technical orientation. But it is also more inclusive in another sense. While the clean tech concept also has a market orientation and is a concept very close to the eco-innovation concept, the eco-innovation concept has the advantage that it encompasses the entire innovation process from idea generation to value creation on the market; i.e. the concept puts focus on the innovation process per se and not only on varies types of production processes or products. This also means that the concept can be linked to the wider "sustainable consumption and production" concept (SCP), though the two concept areas have been little linked so far (see though Andersen, 2008, Tucker et al. 2008).

There are basically two ways a firm may attract green rents on the market: Either by acquiring a premium price for its green reputation or product, or to reduce production costs by achieving greater resource efficiency or reducing the costs of costly emissions. For the firm the greening process appears as turbulent changes in the selection environment, entailing new legitimacy needs and/or requirements for innovations. Different empirical studies have shown that incentives for engaging in eco-innovation vary widely for different types of firms and sectors. (Malaman, 1996, Ulhøi, 2000; Horbach (ed.) 2005, Kemp and Pearson, 2007). Central for an understanding of eco-innovation dynamics is to view *the firm not as polluter but as eco-innovator*. This assumption opens up for a radical redefinition of different firms' and sectors' role in the eco-innovation processes. Traditionally firms' environmental role has been defined by their direct environmental impacts, i.e. whether the firms production process or product belongs to a heavy polluting or energy intensive industry or not. According to the eco-innovation framing it is the impact a given firm has on the eco-

innovation process that is of interest, both form a firm strategizing perspective and from a policy perspective.

The linked nature of the innovation process means that all firms play a role for the eco-innovation process, including none the least service firms, though their direct environmental impact may be small. We need, however, more empirical studies and theoretical analysis for a wider understanding of the patterns in firm eco-innovative behavior. For this type of in-depth analysis of eco-innovation dynamics on the market we need more detailed taxonomies of eco-innovations. This exercise goes beyond this paper, but for early thoughts on a taxonomy of eco-innovations see (Andersen, 2008b). The very high focus currently on low-carbon technologies is an example of shifts in the orientation among different eco-innovations that we need to pay more attention to in order to understand eco-innovation dynamics.

3. Eco-innovation and the greening of markets

For a more full understanding of eco-innovation dynamics, we need to identify the changing conditions for these over time as markets are going greener. Following evolutionary economic thinking the greening of markets should be seen as a specific historic phase and part of a larger global green techno-economic paradigm change.

This section seeks shortly to discuss the core different stages in the greening of markets and the implications these have for eco-innovation dynamics. The discussion is purely schematical as there are currently insufficient data to analyze the greening of markets. Existing statistics mainly cover the category A eco-innovations (pollution- and resource handling technologies and services), while category B, the innovations which are greener than the alternatives, are more or less left out (see (Eurostat/OECD 1989; Malaman, 1996, Hitchens, et al. 1998, Heaton and Banks, 1999; 2002, Rand, 2000a, 2000b, Andersen, 2002, Ecotec 2002, Esto 2000a, Frondel, Horbach and Rennings 2005, European Commission 2006, Johnstone, 2007, OECD, 2007a, 2007b, 2008, 2009).

What then, do we mean by a greening of markets from an evolutionary perspective? In the following discussion insights are used from the innovation cycle literature, the innovation systems literature and the technological paradigm literature.

Greening of markets as part of a techno-economic paradigm change

Many researchers, mainly evolutionary economists, have pointed to the rise of the greening of markets as part of an overall techno-economic paradigm change (Summerer 1989; Kemp and Soete 1990; Kemp, 1994; 1996; Gladwin 1993; Freeman 1992, Andersen, 1999, 2002, 2008b). Lately there is also much reference in the climate debate of the shift from a high- to a

low-carbon economy as a paradigm change (Unruh, 2000, 2002). There has, however, been little theoretical discussion about this.

Theories and studies of innovation cycles argue that some changes in technology have so pervasive impacts on the economy that they will entail a techno-economic paradigm change (Dosi, 1982; Freeman and Perez, 1988; Perez, 2000, 2002). Neo-schumpeterian theory emphasize the long wave relationship between economic and technological development arguing that such fundamental technological changes bring discontinuity in economic development but also act as important engines of economic growth (Freeman, 1982, Freeman and Soete, 1997, Freeman and Louca, 2004). It is her argued that the greening of the economy is of such a nature and scope that it has come to act as such an engine of economic growth and transformation.

The greening of the economy is, however not about systemic technological change in a classical sense, as eco-innovation, as already discussed, is not á technology but more about some (environmental) features which come to act as a market parameter and impacts on all types of innovations. In this way the process of the greening of markets resembles more the pervasive changes of the economy associated with the rise of general purpose technologies such as ICT, biotechnology and nanotechnology. More studies are needed to look into the similarities in these processes (see e.g. Andersen and Rasmussen, 2006).

The greening process is, as argued, about the degree to which environmental issues are becoming integrated into the economic process. Fundamentally this means that environmental parameters are included in the selection processes on the market. As the market is growing greener, green competitiveness becomes increasingly important and influences on the selection of products, but very much, and for many companies and sectors more important for their green competitiveness, on the selection of employees, suppliers and customers, learning partners, financial institutes etc.

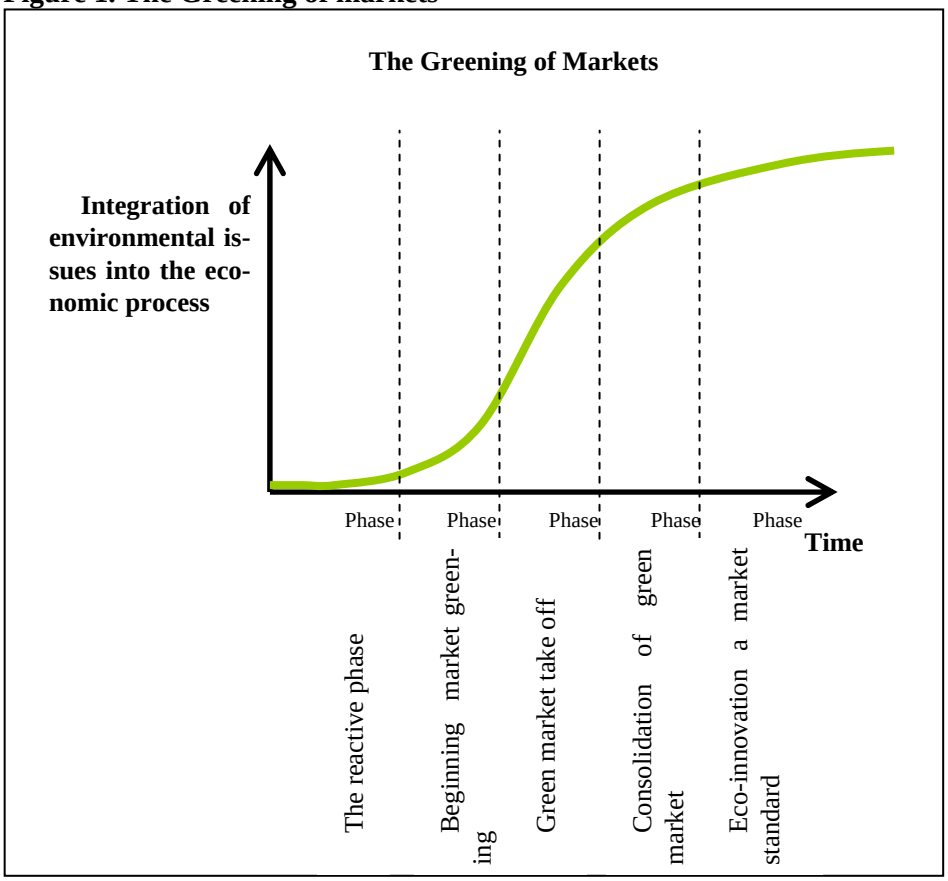
The innovation cycle literature informs us that grand systemic change processes tends to follow certain patterns of development. The stages in the greening of markets we may perceive as being of a similar nature to those of other innovation cycles going from the formative fluid phase to consolidation around a dominating design (Abernathy and Utterback 1984; Teece 1986).

The greening of markets is associated with co-evolutionary processes where eco-innovations evolve alongside new (green) market supporting institutions (communication standards, technical standards, other policy measures..) new (green) capabilities grow while changes take place in the economic organization of production and learning. Gradually, new green entrepreneurs enter and seek to compete with the dominating incumbents on environmental parameters and none-green actors are winnowed out. As the green market becomes more established, none-green sectors and entire technologies may be threatened by competing new greener technological

trajectories. In the final phase eco-innovation has become a market standard and, to use Nelson and Winther's seminal term (1982) the "easy and natural innovation" which by now is routinized and mainstream.

Below the stages in the greening of markets are illustrated.

Figure 1. The Greening of markets



Source: Own source

The figure illustrates five different stages, during which the conditions for eco-innovations differ markedly.

We may perceive of the greening of the economy as a specific historical phase evolving in the global economy, though with considerable regional and sectoral differences. Pioneering the development has been the developed economies. The first long phase, beginning in the 1950s as the environmental agenda arose, has prevailed for over 30-50 years and has cemented the environment as a burden to business. The shift between phase 1 and 2, we may point to the end of the 1980s and beginning of the 1990s, when we saw more product oriented environmental policies ("integrated

product policies" and clean technologies support programs) emerging and the first environmental strategizing among pioneering companies. The critical shift between phase 2 and 3 towards the green market take off is happening right now, starting 2-3 years ago and still accelerating. This shift has been revolutionary in character, taking very quickly root considering the long phase 1 and the rather slow phase 2. It is currently difficult to say anything about when a transition to phase 4, market consolidation, and phase 5, eco-innovation as a widely recognized market standard, will take place.

It is suggested to term the final stage the "*green learning economy*" at the global level and at the national and regional level, we are referring to the "*green innovation system*".

The conditions for eco-innovation vary considerable in the different stages. In stage one, innovation activities are purely a response to policy initiatives, which is mainly the case I phase 2 too. Here the pioneering eco-innovators experience very high friction to developing and marketing eco-innovations as the capabilities and market insitutions are not in place. In phase 3, our current phase, the green market take-off where innovation is beginning to move in a green direction, there is still very high, but rapidly diminishing friction to eco-innovation. Characteristics of this phase is the very uneven character of the greening of the economy, with varies actors in the global value chains being in very different stages in their greening process (see Andersen, 1999). Hence in this stage green co-creation is difficult and the green transaction costs are very high though with considerably differences in different markets. In phase 4 there are sunk costs to greening and it has become considerable easier to engage in eco-innovations, but the economic returns may also be lesser. In phase 5 the ultimate green learning economy, eco-innovation has become the easy innovation that routinely is being pursued and technology moves in a green direction. The economy is then characterized by 4 elements:

1) a high eco-innovative capacity
2) a selection environment that favours eco-innovation
3) an efficient organization of green production and learning across actors (firms and knowledge institutions) in the national innovation system
4) a strong green knowledge base

In such an economy it is attractive and easy for companies and knowledge institutions to engage in eco-innovation because supporting market institutions and relational assets are in place and eco-innovation has become the natural innovation that routinely is being pursued.

This argumentation points to a likely positive green future in the green learning economy, but it is important to stress that we are still far from

reaching the more efficient phases 4 and 5 when the market forces can work more on their own. There is still very high friction to eco-innovation, which may mean that the transformation to the green learning economy is going to be slow and difficult and very depending on appropriate policy measures, particularly until phase 3 and 4 are reached in most part of the economies around the globe and the self-reinforcing market forces will come to work more on their own. It is likely that there, as hitherto, will be shifts in the intensity of the greening process. The techno-economic paradigm discussion is important in explaning important elements of the greening of markets in two ways. First, and widely recognized, it puts emphasis on the pervasiveness, radicality and path dependency of the greening process. The economy is currently highly locked-in to carbon based and wasteful technologies and the shift to a low carbon, resource-efficient society is therefore likely to be costly and entail considerable creative destruction. Some sectors and economies may suffer substantially in the process and offer resistance to the greening of the economy.

Secondly, and much neglected, the paradigm discussion is even more important because it points to the neglected cognitive roots underlying the paradigm changes of the economy. Economic research into technological paradigms and trajectories emphasize how technology development, similar to scientific work, follow certain heuristics (Nelson and Winther 1982, Dosi, 1982). A research organisation's or firm's knowledge base is characterized by certain heuristics, which are theory-laden and upholding inner consistency (Dosi, 1982). Reigning technological paradigms embodies strong prescriptions on the directions of technological change to pursue *(positive heuristics)* and those to neglect *(negative heuristics)*. A techno-economic paradigm also entails a notion of "technological progress" which guides the direction of companies and knowledge institutions search processes (Dosi 1982). Hence the evolving green techno-economic paradigm change we may interpret as the rise of a new notion of *green (technological/innovation) progress* which influences on the search processes of firms and knowledge institutions (Andersen, 1999). It is argued that the greening process entails specific green heuristics which lie behind these processes (see Andersen, 1999, 2002). Fundamental in the green heuristics is some notion of resource efficiency, i.e. to achieve maximum service with minimum resource use and overall environmental impact [1](Daly, 1984, WBCSD 2000.) and overall an attention to the environmental impact of an agents given activity (Andersen, 1999). At the level of the economy it is similarly possible to define a "green technological trajectory" at a very fundamental level. We may hence perceive of the green techno-economic paradigm as a shift from, and a competition between a

[1] The concept of resource efficiency is ised here similar to the concept of eco-efficiency. The term resource efficiency has the advantage that it is immediately meaningful which is not the case for the eco-efficiency term. See WBCSD 2000 for a full discussion on eco-efficiency.

"wasteful" trajectory, with little attention to the exploitation of resources in (firm/scientific/family) normal problem solving activities, towards a "resource efficient trajectory" where there is strong attention to an efficient use of resources (the sink and the source functions, the life cycle impacts) in normal problem solving activities (see Andersen, 1999).

Despite the complexity of eco-innovation processes, there is hence some fundamental shared learning associated with the rise of eco-innovations and the greening of the economy.

This discussion emphasis that the greening process is more than a technical substitution process, from none- green to green technologies or carbon based to none carbon based technologies, but a more fundamental learning process, involving the creation of new understandings, values, search rules and capabilities and the creative destruction of old values, practices and capabilities. The eco-innovation agenda is closely, and increasingly so, linked to the recent CSR (corporate social responsibility) agenda which has even stronger moral association than the eco-innovation concept with its overall focus on integrating ethical dimensions into firm strategies and operations. This is none the least related to managing globalizing value chains such as setting environmental and social demands on suppliers in developing and catch-up economies (Tukker et al. 2007). So far, however, the eco-innovation and CSR research areas are little linked, the eco-innovation being mainly dealt with in the economic innovation literature and the CSR research mainly being of a sociological or management like research (see though Andersen, 2007). The greening of the economy is the rise, or possible return of, the political economy where it is evident that values matter for the economic process and that innovations are always value-loaded (see also Freeman, 1992).

In evolutionary economic theory knowledge and the ability to learn is seen as the key source of competitiveness in the intense globalizing economy, hence the notion of the global knowledge economy or the learning economy (OECD, 2000a, Lundvall, 2002, 2005). The learning aspects are considerable when it comes to eco-innovation, hence the suggested notion of the green learning economy. Much learning and creative destruction has to take place for the green economy to evolve, and the quest for a sufficient resource efficient economy will never end. These factors present a challenge to firms but also a major business opportunity which fit well into the changing competitive conditions of the knowledge economy.

It is likely that, as experienced hitherto, there will be waves in the intensity of the greening process in the future. However, the process is, as any other change process, cumulative and there is no longer any doubt that the environmental agenda is becoming an integrated part of and an important driver for economic development in the knowledge economy. How important remains to be seen.

Conclusions

Research into eco-innovation, and generally speaking the environmental and climate agenda, has hitherto had a strong focus on policy issues and effects, while little attention has been paid to the innovation dynamics involved; especially theoretical clarifications are lacking. This paper has argued that the concept of eco-innovation may best be understood from an industrial dynamics perspective, based on a combination of evolutionary economic and resource based theories. The paper has focused on a basic discussion on defining and understanding eco-innovation arguing that it needs to be linked up to a discussion of the greening of markets and overall economic evolution. While eco-technologies usually are defined in technical terms this paper has suggested to interpret eco-innovation in economic terms. Eco-innovation from the suggested perspective is defined as *innovations that attract green rents on the market.* Hence the concept of eco-innovation reflects innovative changes in the economic system measuring *the degree to which environmental issues are becoming integrated into the economic process.* Following this definition the eco-innovation concept is inherently linked to green competitiveness and the greening of the economy.

The evolutionary perspective suggests that the greening of markets should be seen as a specific historic phase and part of a larger techno-economic paradigm change towards a "green learning economy". Using innovation cycle, innovation systems and techno-economic paradigm literature the paper identifies five phases in the greening of markets and describes the co-evolutionary innovative processes which transform the economy. Each phase is characterized by very different eco-innovation dynamics. In the current green market take of phase (phase3) the eco-innovation era is beginning to take root, characterized by very uneven greening, high friction to eco-innovation and great uncertainty. As the environment increasingly becomes a selection parameter and a routine practice, the friction to eco-innovation diminishes and the green market consolidates (phase 4); in the ultimate phase 5 the selection environment favours eco-innovations, eco-innovation has become the routine, the "easy and natural" innovation to use Nelson and Winters seminal term (1982), and innovation moves in a green direction.

Taking on a long run perspective on the economic process attention has been brought to the key role the history of the greening of markets has for the eco-innovation dynamics today. A strong paradigmatic explanation of eco-innovation dynamics has been suggested. The paradigm discussion forwarded puts emphasis on the pervasiveness and path dependency of the greening process. But, and less recognized, it also puts attention to the cognitive roots underlying the economy, arguing that fundamentally the eco-innovation processes should be seen as a learning process involving the creation of new understandings, values, capabilities and search rules, hence the suggestion of situation eco-innovation as part of a move towards the green learning economy.

The paper concludes that the concept of eco-innovation in important ways renews the environmental agenda. First, it offers a broader perspective on eco-technologies and -services than hitherto seen in emphasizing the innovation process per se rather than products or production processes. Secondly, and most importantly, it offers a very different framing of the society-nature relation to orthodox economics because, as defined here, it intersects environmental degradation, innovation and dynamic market processes. As such it represents a new rationale for firm strategizing as well as policymaking and captures important aspects of the changing competitive conditions of the knowledge economy.

The arguments in this paper have been quite fundamental and should form the basis for more particular studies of eco-innovation dynamics. Such as looking into the innovation dynamics for different eco-innovation sub-categories, for regional and sectoral differences in the eco-innovation dynamics, as well as investigating interfirm eco-innovation dynamics and relations to the CSR and SCP agendas more closely.

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