Innovating Innovation Policy
Rethinking Green Innovation Policy in Evolutionary Perspective

Abstract

Advanced environmental standards such as sustainability require substantial improvements in the environmental performances of present technologies. Governments are faced with the challenge to design green innovation policies able to support producers and users of technologies to comply with such high standards. The paper proposes an evolutionary approach on the dynamics of socio-technological change and innovation, as an analytical basis for the design of such green innovation policies. The main idea suggested is that evolutionary theory can be helpful in clarifying not only the novelty and greenness of innovation, but also the processes of technological variation emergence and selection at various system levels. Such an understanding would facilitate policy-makers in identifying the most appropriate intervention points and styles in order to maximize the scope, quality and endurance of green innovation.

The paper departs with the conceptualization of "greenness" of innovation in section 2, and proceeds further, in section 3, with an evolutionary-based inquiry in the innovation dynamics within the economic system, the science/technology system and at their interface. Based on such an approach, section 4 proposes a framework for the design of green innovation policies, taking into account the multidimensional institutional environment of innovations. The framework suggests that green innovation policies should be best conceived by simultaneously affecting selection processes in the three main systems, for which the appropriate combination of intervention points and styles of regulation should be underpinned.

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1 Introduction

While the range and extent of environmental hazards increasingly challenges industries to adopt green technologies and green product designs, at the same time, public authorities are challenged to "green" their innovation policies and programs.[2] For this reason, many countries develop green innovation programs, in order to support and accommodate the development and diffusion of new, more environmentally benign technologies. However, these programs appear to be rather restricted in terms of both the extent of novelty induced and the associated improvements in environmental performances, if any. One of the causes seems to be restricted and deterministic conceptions of innovation dynamics underlying these policies and programs that predominantly assume barriers and pitfalls in decision making at firms' level. Relieving these barriers by incentive-based means, such as financial programs and tax measures, is assumed to be the major objective of innovation programs in order to adopt to environmentally benign technologies. Undeniably, these measures do have some impacts but innovations accommodated by such measures turn out to be rather incremental in nature and restricted in reach and scope. Moreover, the green component, which is the net improvement in environmental performances brought about, is in most cases unsatisfactory. Basically, they induce only "stand alone", smooth improvements, which by far will not satisfy the technological needs to comply with advanced environmental standards such as "sustainability". In order to meet such advanced standards, more radical innovations are needed that have the potential to engender "discontinuity" of incumbent environmentally hazardous technological tracks and to induce more advanced green innovation policies and programs able to initiate and support these innovations.

Assuming the need of public innovation programs to initiate and to support the emergence of green technologies in the economic system, this paper argues that an evolutionary conception of technological change and innovation is most helpful to design such green innovation policies and programs. Evolutionary theory has developed a set of notions providing for a more sophisticated understanding of the structure and dynamics of socio-technical change processes. In this paper we like to illustrate how these notions can be used to improve innovation policies. Therefore, the central question to be addressed in the present paper is, how to design green innovation policies, given the evolutionary dynamics of socio-technological change and innovation?

This question will be tackled as follows. Section 2 of the paper starts with elaborating a conceptualization of "greenness" of innovation. Drawing on the conception of innovation suggested by Saviotti (1996), we develop a notion of "green innovation" to distinguish "green" innovation from innovation in general. Then section 3 analyzes the core elements of the dynamics of technological change and innovation Here we draw on evolutionary economists that have elaborated theories regarding the embeddness of innovations in the economic system, and

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[2] This paper conceives of *green* innovations as improvements in technology perfromances aiming at the reduction of their environmental impact. *Green innovation policies* are understood as public policies and programs stimulating and supporting the development, application and diffusion of green innovations.

sociologists of technology who tried to open-up the black box left behind by economists, by attempting to understand the "change event" of innovation emergence. Based on the findings in section 2 and 3, section 4 then suggests a general framework for the design of green innovation policies, able to increase the "greenness" of "variation" produced by innovations and to influence selection processes towards the adoption and long-term sustenance of the most environmentally benign technologies. Finally section 5 draws some conclusions. The focus of the paper is predominantly analytical and not empirical.

2 Mapping 'green' innovations

Evolutionary economists mainly concentrate on the impact of innovations on the structure and functioning of the economic system. From the perspective of environmental quality and sustainability, however, the environmental performances of new technologies are the major focus. Therefore, green innovation policies need to draw on a clear conceptualization of the greenness of technological innovations. This section suggests a conceptualization of 'greenness' of technological innovation.

In his book, "Technological evolution, variety and the economy"(1996), Saviotti has suggested a twin-characteristics representation of technologies. According to Saviotti a technology may be depicted with the help of two sets of characteristics: technical characteristics - constituting the inner structure of a technology, and service characteristics - describing the service or functionality for its users (see Figure 1). In this way, he suggests, the differences between technologies can be more easily mapped, as technologies differ either in their technical or in their service characteristics, or in both. But, more importantly, the twin representation helps to distinguish conceptually between incremental and radical innovations. An incremental innovation is conceived as a change in the level or value of technical/service characteristics, whereas a radical innovation is conceptualized as a *qualitatively* different internal structure of a technology as compared to the previous one, meaning the renewal of the whole set of technical/service characteristics.

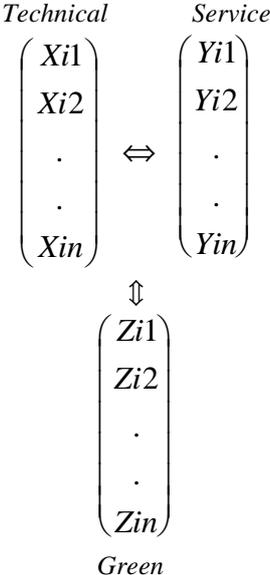Figure 1: Technical and service characteristics of technologies[3]

$$
\text{Technical} \qquad \text{Service}
$$

$$
\begin{pmatrix} Xi1 \\ Xi2 \\ . \\ . \\ Xin \end{pmatrix} \Leftrightarrow \begin{pmatrix} Yi1 \\ Yi2 \\ . \\ . \\ Yin \end{pmatrix}
$$

To move the spotlight on the environmental performances of technologies and the consequences of innovations for the environment, the twin-characteristics representation of technology suggested by Saviotti needs to be amended, for two reasons. Firstly, neither the change of technical characteristics, nor the alteration of the service characteristics will necessarily improve the environmental performances of technologies. The analysis of the changes in the technical/service characteristics of a technology per se cannot directly support

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[3] Figure is taken from Saviotti, 1996, 64.

an understanding of the consequences of such innovations for the environment. Secondly, the qualitative change of the internal structure of a technology is not a guarantee for superior environmental performances. This is why we suggest to add to the twin-characteristics representation of technology suggested by Saviotti, a third one, that can be labeled as "the green characteristic of technology" (see Figure 2).

Figure 2: Triple characteristics representation of technology

$$\begin{array}{cc} \textit{Technical} & \textit{Service} \\ \begin{pmatrix} Xi1 \\ Xi2 \\ . \\ . \\ Xin \end{pmatrix} \Leftrightarrow & \begin{pmatrix} Yi1 \\ Yi2 \\ . \\ . \\ Yin \end{pmatrix} \\ & \Updownarrow \\ & \begin{pmatrix} Zi1 \\ Zi2 \\ . \\ . \\ Zin \end{pmatrix} \\ & \textit{Green} \end{array}$$

Green characteristics may refer either to the technical or to the service dimension of a technology. Some examples of technical characteristics for the energy sector are the conversion efficiency rate of natural resources and the amount of resources incorporated in the technology. When innovations affect these characteristics, the environmental impacts of the technology will be changed as well. In this case innovations will alter, therefore, both the technical and the green characteristics. Such innovations can be considered to affect the *internal* part of the green characteristic component.[4] Further, some examples of environmental impacts associated with the service characteristics of automobiles are the release of atmospheric emissions. Changes in the service characteristics can attract changes in the associated environmental impacts. In this case innovations will alter, therefore, both the service and the green characteristics. Such innovations can be considered to affect the *external* part of the green characteristic component. Consequently we can disentangle two sub-components for the green characteristics of technologies: the internal sub-component, associated with the technical characteristics, and the external sub-component, associated with the service characteristic. By adding the green characteristic component to the representation of technology developed by Saviotti, we can conceptualize the greenness of different types of innovations as suggested in Table 1.

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[4] This is based on applied thermodynamics. See Cornelissen, 1998.

Table 1 Green innovations

Characteristics of technology		Technical characte-ristics	Service characte-ristics	Green characteristics		Greenness of innovation
				Internal green	External green	
Level-characteristic changes	1.	Yes/No	Yes/No	No	No	Neutral
	2.	Yes	Yes/No	Yes	No	Incremental
	3.	Yes/No	Yes	No	Yes	Incremental
	4.	Yes	Yes	Yes	Yes	Incremental
Internal structure changes	5.	Yes/No	Yes/No	No	No	Neutral
	6.	Yes	Yes/No	Yes	No	Radical
	7.	Yes/No	Yes	No	Yes	Radical
	8.	Yes	Yes	Yes	Yes	Radical break-trough

Table 1 illustrates that not every change in the level characteristics or the internal structure of a technology is also a green innovation. From a green perspective, the least helpful innovations seem to be those changing certain aspects of the technical and service characteristics of a technology, or even its complete structure, without inducing any progress or only incremental improvements in their environmental performances (lines 1 to 5 in the table). Such innovations might be interesting from a technical-scientific or economic point of view, but less attractive from environmental standpoint. They are not the types of changes that "green innovation policies" should be meant to stimulate.

The most significant green innovations are those producing a qualitative change in the technical internal structure of a technology, accompanied by in progress in both the internal and the external green characteristics of technologies. The challenge is to combine such types of innovations with at least the maintenance of the service level (indicated by "no" change in the table, column 3, lines 6-8), or the improvement of technology's functionality (indicated by "yes" in the table). This is because consumers are hardly willing to change consumption patterns or to compromise service standards in exchange for environmental quality. Such changes will considerably improve the green profile of the technology and are, therefore, highly "desirable" (lines 6, 7 and 8 in the table). These are the changes that green innovations policy packages should lead to, provided they are properly designed. The most powerful type of green innovation is shown in line 8 of Table 1. This represents the case of a qualitative change of the internal structure of a technology, which improves all three types of characteristics of a technology – technical, service and green (both internal and external). In this case the innovation represents a real technological "break-trough", by setting up a completely new technological trajectory which is intrinsically green in structure and service.

Green technologies are assumed to integrate highly performing and competitive technical and service characteristics, with the best conceivable internal and external green characteristics. And for this, green innovations are considered to be those technological advancements that contribute to such technological profiles. Drawing on the idea of Saviotti who considers technologies/artifacts as interfaces between inner and outer environments, green characteristics may be assumed to represent the interface between the technical characteristics of a technology, on the one hand (the inner environment), and the service characteristics of technologies, on the other (the outer environment). This approach is displayed in Figure 3. Green characteristics can be, therefore, viewed as the mediating device between the two environments.

Figure 3 The green interface between technical and service characteristics of technology

Technical characteristics	⇔	Internal green characteristics	⇔	External green characteristics	⇔	Service characteristics

Consequently, the challenge of green innovation policies is to support the bridging of the two environments, by integrating the improvement of green characteristics with the advancement of both technical and service characteristics of technologies. In this way, green innovation policies may encourage the emergence of sturdy technological trajectories that incorporate minimum (or no) environmental hazards. To support such green innovations, the policy repertoire should address basically three issues:

- the technical characteristics of a technology – taking into account that the main selection processes occur in the science/technology system;
- the service characteristics of a technology – taking into consideration that the main selection processes are unfolded in the economic system; and
- the exchange of these two characteristics – paying due consideration that these exchange processes occur at the interface between the two above mentioned systems.

The next section will elaborate these issues by analyzing the dynamics of socio-technical change and innovation based on notions from evolutionary theory.

3 Dynamics of technological change and innovation

3.1 Variety and selection in the economic system

Evolutionary theory, has developed a set of ideas, concepts and theories which are helpful in explaining why technology predominantly gradually changes and why technological innovations tend to be rather incremental.[5] Figure 4 summarizes the core-argument of the evolutionary mechanism.

Figure 4
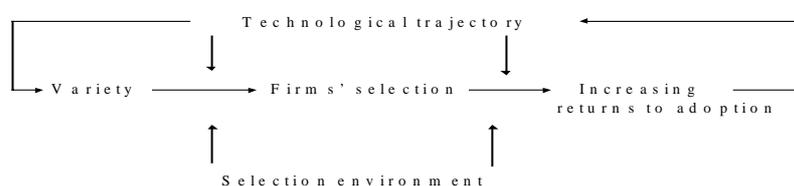
In the evolutionary tradition, firms in need of technology behave in a fashion that makes them resemble "merely the incubators and carriers of 'technologies' and other practices that determine 'what they do' and 'how productively' in particular circumstances" (Nelson, 1995, 68). These routines determine to a great extent the set of alternatives firms tend to choose in

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[5] Hodgson, 1994; Nelson, 1995 and Saviotti, 1996 provide for detailed overviews of evolutionary thinking.

solving problems they are facing, or to search for new and better technologies. These routines are basically the result of learning processes a firm has internalized in problem solving and to respond to its (changing) environment. Whether these routines are effective or not is basically decided by the firm's ability to continue its profitability and to maintain and increase its market position. Firms rely on routines because of the uncertainties incorporated in decision-making processes. In order to reduce these uncertainties and to avoid risk, firms tend to fall back on routines and rely on those alternatives in decision making that have proved to be effective in the past. In other words, firms tend to stick to their own corporate history of routines and practices to respond effectively to their environment. They cannot take any risks in this regard and this basically holds them back from "technological experimentation."

Naturally, firm's routines and standard operating procedures are not fixed, but do evolve and change in order to keep track with changes in the firm's environment. Firm's ability to match the changing requirements of its environment is vital to survive. But here to, the adjustments tend to be rather smooth and incremental which is reflected in the cumulative character of the firm's knowledge. Firms develop their own knowledge base in a cumulative way meaning the "learning of newer pieces of knowledge requires a knowledge of the previous ones" (Saviotti, 1996, 171). Because of the risk avoiding nature of the search process, it becomes easier for a firm "...to acquire new external knowledge the more similar it is to the firm's pre-existing internal knowledge" (ibid, 172). According to Saviotti, as long as the firm's environment does not provide for a radical change in knowledge, "...firm's knowledge is likely to be cumulative and to display increasing returns to adoption. This implies that firms wanting to enter a particular technological area would face a knowledge barrier. Conversely, firms having accumulated knowledge in a technological area will tend to be locked in that area. Furthermore, if there are multiple options to the development of a technology, after a firm has opted for one of these it becomes extremely difficult to switch to a different one. In other words, in a number of cases technological knowledge can show increasing returns to adoption and, therefore, display irreversibility and path dependence in its development" (Ibid, 172). These trajectories become harder to change the longer the path of their development is. "Increasing returns" appeal to the cumulative and self-reinforcing advantages a technology may enjoy once it has gained a dominant position (Boschma and Lamboy, 1998). As Nelson expresses it: "...there are dynamic increasing returns, in that the more a particular technology is employed, the greater its attractiveness relative to its competitors" (Nelson, 1995, 74). Or differently stated, "...technology is not chosen because it is efficient, but it becomes efficient because it has been chosen" (Rip and Kemp, 1998, 353-4).

In evolutionary thinking the notion of *selection* is important in the explanation how inventions get nestled in the economic process, and which are the reasons for their success or failure. The evolutionary notion of selection environment is very important for innovation and diffusion policy, because the environment incorporates to a great extent the conditions for the survival of the new technologies. Discussing the survival of firms based on the same evolutionary scheme, Nelson argues that whether firms will be successful or not, is basically decided by "ex post competition". The same can be extended for the survival of new technologies. It is difficult to predict beforehand the winners and losers among new technologies, because the race is decided by a complex set of factors and dynamics incorporated in the "selection environment". The firm's environment may be assumed to consist of organizations grouped as competitors, users/consumers, suppliers of input, equipment, knowledge, human capital and regulating institutions. The environment may have certain attributes, such as complexity, diversity, interactivity and rate of change, both qualitatively and quantitatively (Saviotti, 1996,

174). Organizations in and attributes of the firm's environment are assumed to influence the firm's adaptive behavior.

3.2 Variety and selection in the science/technology system

The structure and dynamics of the "invention-side" of innovations are of minor concern in economically oriented evolutionary thinking. There, innovation - in the sense of "novelty creation" - tends to be "summarized" under the notion of "change event". Then, the black box is left behind un-opened and the focus of analysis turns back to the processes of selection and nestling of technology in the economic system. In reality, these "change events" hide, however, a whole complex of R&D-activities occurring in highly institutionalized scientifically and technologically oriented environments and this is where sociologists of technology-dynamics are interested in. Next to the economist's analysis, their story too is helpful to better understand the logic of technological change and innovation.

Drawing on evolutionary economics, sociologically oriented evolutionary approaches developed a specific focus in the analysis of technological change processes. Sociologists tend to concentrate on the understanding of the structure and dynamics of technological change processes in the science-technology system and are less concerned with their meaning and impact on the economic system. For this reason, sociologists tend to position themselves as *quasi*-evolutionists (Rip and Kemp, 1998). For sociologists, the "lock-in" in certain trajectories is accounted for based on the idea that today's technological logic builds upon the heritage of the past and today's logic may be found, at least partly, in yesterday's science and technology efforts.

The concept of technological regime has been suggested to map the collective variant of the idea of cumulative knowledge and technology at the system's level. According to Nelson this concept has been introduced: "(...) to refer to the set of understandings about a particular broad technology that is shared by experts in a field, including understandings about what a firm needs to be doing to operate effectively in that regime" (Nelson, 1995, 79). Rip and Kemp provide a more sociological oriented definition of a technological regime, taking also the "knowledge production side" into account. They state that "a technological regime is the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artifacts and persons, ways of defining problems - all of them embedded in institutions and infrastructures" (Rip and Kemp, 1998, 338). This sociological conception of technological regime is very wide but it nicely points to the "materialized" heritage of technological change and innovation. This heritage incorporates ideas, conceptions, artifacts, routines, habits, customs, skills, standards and institutions that all together determine and shape and condition present search processes for better technologies.

Three dimensions of the science/technology system bear special importance: the cognitive, the institutional and the technological dimension. The cognitive dimension, refers to the ultimate basis of technology emergence, that is pure fundamental scientific knowledge. This knowledge is cumulative in nature, building on centuries of ideas, science and research and encompasses a set of fundamental scientific laws, such as the laws of thermodynamics, or the laws of conductivity and electrical resistance. Based on these laws, scientific and technical disciplines have developed. These disciplines "produced" the multi-disciplinary scientific knowledge base upon which current technological regimes are drawing. Furthermore, the

science/technology system evolved over centuries into a highly institutionalized structure of science and knowledge "production", a structure basically constituted by professions, particular organizations and specific science communities. Together they represent the institutional device by which scientific and technological knowledge evolved over time.[6] The technological dimension of the science/technology system refers to the "materialized" knowledge reflected in hardware technologies - the artifacts that have been developed by application and combination of certain technological principles.

According to sociologists, the science/technology system has its own logic and dynamics that contributes to the emergence and continuation of certain technological trajectories and to the evolution of technological regimes (Rip and Kemp, 1998). We consider that, like in the economic system, the innovation dynamics within the science/technology system follow the same elementary mechanisms of variety and selection. Beside this, scientists and engineers are, like firms, faced with the temptation of increasing returns to knowledge, but constrained, in the same time, to follow the signals for change launched by the selection environment in order to survive. Science has become a highly differentiated, specialized and compartmentalized activity, not only among disciplines, but also within single disciplines. But scientists involved in all this multitude of intra- and inter-disciplinary branches have one common goal – to secure the necessary resources in order to continue their activities. To achieve this, they have to perform up to the expectations of their resources suppliers and to adjust the focus of the scientific research, so as not to endanger their survival. This can explain the risk-avoiding behavior of scientists and research clusters and the fact that "variations", in terms of both fundamental knowledge and technological know-how, tend to be path-dependent. Consequently, the innovation dynamics within the science/technology system are assumed to be driven by the same kind of logic that underlies the dynamics and selection of technology in the economic system and the emergence of certain technological trajectories and paths. This analogy with the economic system is displayed in Figure 5.

Figure 5
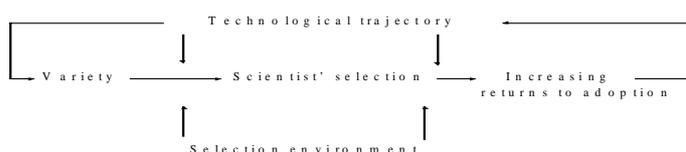
As Figure 5 illustrates, the innovation dynamics in the science/technology system can be understood through the same evolutionary scheme as in the economic system. However, in advanced economies, it is the tied up of both systems that brings about technological change and innovation. Techno-economic networks are suggested by evolutionary theory to cover the mediation between the science/technology system and the economic system.

3.3 Interface between the science/technology and the economic system

In advanced economies, techno-economic networks have emerged as bridging devices between the science/technology and the economic system. "The growing knowledge intensity of economies seems to be accompanied by a growing degree of interaction of firms and other

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[6] For an extensive analysis on this theme see for instance Schaeffer, 1998.

organizations" (Saviotti, 1996, p. 12). Techno-economic networks can be understood as "a coordinated set of heterogeneous actors, (...), which participate collectively in the development and diffusion of innovations, and which organize, via numerous interactions, the relationship between research and the market place" (Saviotti, 1996, 197). In advanced economies, there seems to be no longer a clear distinction between the science/technology system and the economic system. Both systems are becoming highly interconnected, while innovation increasingly becomes a joint effort of science and business. As a result of this expanding collaboration, intermediate devices have developed at the interface between the science/technology system and the economic system (Rip and Kemp, 1998). These devices have become constituent part of the institutional environment in which technology is transmitted.

However, not only institutions, agents and agent-configurations act as mediating devices between the science/technology system and the economic system, but especially also technology itself. According to Saviotti, technologies/artifacts can be considered as interfaces between inner and outer environments, where the technical characteristics are assumed to represent the inner environment while the service characteristics act at the interface with the outer environment - the market place. The "correspondence (or imaging) between technical and service characteristics, constitutes the coupling of technological knowledge to market demand. The services performed by a given technology determine how closely it can adapt to the environment in which it operates. If the inner environment is appropriate to the outer environment, or visa versa, the artifact will serve its intended purpose" (Saviotti, 1996, 65). Therefore, it can be assumed that technology bridges the science/technology system and the economic system by exchanging and transmitting knowledge on the technical and service characteristics of a technology. This idea is represented in the upper part of Figure 6.
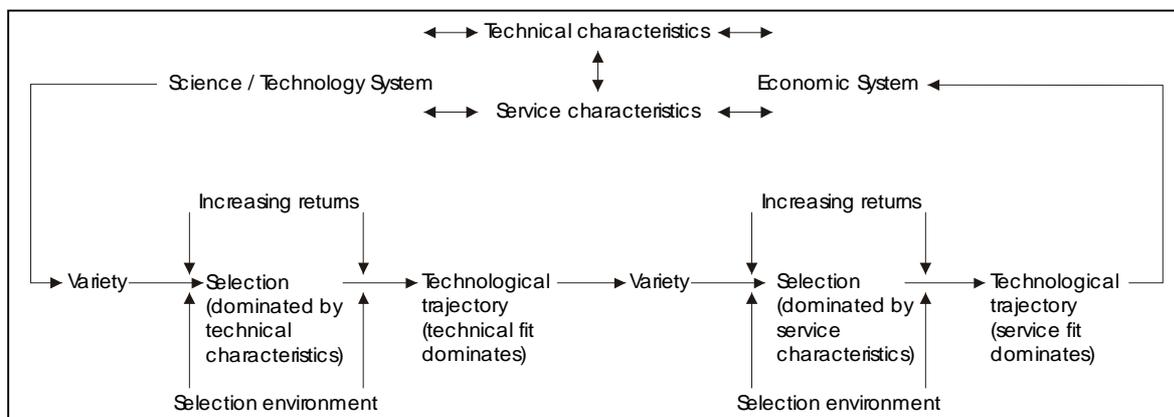

Figure 6

In the science/technology system selection is dominated by criteria related to the technical characteristics of technology (and to a lesser extend to the service characteristics), whereas in the economic system selection is rather dominated by the service characteristics criteria. This is illustrated by the lower part of Figure 6. It can be assumed that the selection processes occur simultaneously in the two systems and at the same time influenced by various factors present in the selection environment.

To summarize, both economic and sociological approaches are helpful in understanding how innovative technological options are being selected and how innovations find their way in the economic system through selection processes. Both in the science/technology system and in

the economic system, the selection of technology is highly institutionalized and strongly influenced by various forces active in the general environment. Neglecting these forces can be risky, both for the scientist/engineer and the firm, and can be threatening for their "survival". By adopting incremental technological choices that are based on the pre-existing knowledge bases, both systems try to minimize the risks associated with technological change and to benefit from the phenomenon of increasing returns. In these way actors in both systems show their preference for the continuation of their activities along the pre-established technological trajectories, and the engagement in only incremental technological changes. Therefore, innovations are confronted not only with cumulating knowledge at the firm level, where technology is actually used, but also with increasing returns to knowledge on the "production side". It is at the interface where the technical and service requirements of technologies meet and where the sociotechnical knowledge base is cumulated.

Public authorities, facing the need "to green" technologies and innovations in order to meet advanced environmental standards as "sustainability", hardly account for the complexities of technological change and innovation put forward by scholars of evolutionary theory. A better understanding of the structure and dynamics of technological change and innovation is a first (and necessary) condition to design more effective green innovation policies, being policies able to induce radical and break-through innovations with substantial reduced environmental impacts. Drawing on both the economists' and the sociologists' contribution to the understanding of the structure and dynamics of technological change, the next section sketches a framework for such policies.

4 A framework for green innovation policies

The challenge to green innovation policies is to find strategies and approaches that can result in radical and break-through innovations endogenously forming new self-standing technological trajectories that have inherent superior green performances, as compared to their incumbents. Drawing on the core argument of evolutionary theory, intervention policies should thus be shaped having in view the selection-mechanisms and criteria underpinning technological change, because it is the dynamics of the selection processes that ultimately influence the emergence of new technological trajectories. Therefore, the potential of innovation policies to contribute to the greening of technological innovations depends on the ability to increase the greenness of variety, in the first place, and to affect selection processes, so as to favor the new technological options that have the highest environmental performances, in the second place, in both the economic system and the science/technology system. This is the core of the lesson taught by evolutionary theory, and green innovation policy is challenged to translate these lessons into effective intervention strategies.

A first step in developing evolutionary based green innovation policies is to identify the points of intervention. Evolutionary theory clearly indicates *where* to intervene, being the dynamics of technological change in the economic and the science/technology system as well as the mediating networks between both systems. It is this multidimensional system, which is assumed to be the intervention domain of green innovation policies and for which evolutionary theory has provides for understanding of its logic and dynamics (see section 3). The structure of this multidimensional system, the decisions and activities of the actors operating in the system as well as the performances of the system provide for the intervention points of green innovation policies.

The second step in developing green innovation policies is to design policy packages of interrelated and mutually reinforcing strategies, in order to profit as much as possible from the catalytic effect of the dynamics of technological change and innovation itself. In general, policy strategies can be more or less coercive, meaning that intervention can take different types, depending on the amount of coercion put on the addressee (Richardson, 1982, Vogel, 1986). For example, in a purely publicly owned hierarchical organization the type of regulation is almost coercive by definition, whereas in a neoclassical free market the coerciveness of regulation is supposed to be minimal, not to disturb the proper functioning of the market. Likewise, public intervention strategies can be assumed to underlie a continuum of coercion (Vedung, 1998), with certain points representing different intervention styles. In this way three so-called basic policy styles can be distinguished:

- a facilitating style, predominantly supporting the selection of green innovations;
- an initiating style, predominantly encouraging the selection of green innovations; and
- an enforcing style, predominantly forcing the selection of green innovations.

In combination, the suggested intervention points and intervention styles provide for a general framework to design evolutionary based green innovation policies. Table 4 displays this framework with in each cell examples of strategies for the greening of "variety" and for the intervention into selection processes. The cells in table 4 suggest examples of interrelated and mutually reinforcing policy strategies that draw on the dynamics of technological change and development. The suggested strategies, therefore, share the common aim of bringing "greenness" of innovation into the dynamics of technological change itself.

Firstly, the table distinguishes between the science/technology system, the intermediate system and the economic system. Section 3 above, analyzed the dynamics in and among these systems and how they shape and change technology. Therefore, each of the systems should be included in the intervention domain of green innovation policy. The basic entrance points for green innovation policy in each system are represented in the second row of the table, by "structure", "conduct" and "performance". Strategies may address the structure of the systems, the conduct of the actors operating in the systems or the performances in the system.

Secondly, the first column of the table represents the three policy styles of intervention and includes the facilitating, the initiating and the enforcing style. Thirdly, the combination of intervention point and the intervention style has been "translated" in examples of more concrete innovation strategies, policies and programs and this is displayed in the cells of the table.[7] It should be emphasized that the strategies suggested in each cell should be read as examples and not as comprehensive sets of strategies.

Fourthly, the table is basically suggested as a tool for policy makers to design green innovation strategies, policies and programs. The table attempts to convey the complexities of technological change and innovation, to make them more accessible for policy intervention. Therefore, the decomposition of real-life - complexities that are analyzed and explained by both economically and sociologically oriented evolutionary scholars - is one of the main tasks of policy analysts and policy designers. To pursue public goals and interests, policy has to

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[7] It should be emphasized that the table is only meant as a policy-mapping device and not as explanatory scheme of technical change.

intervene in these complexities and a first and necessary (but not sufficient) condition, therefore, is to make these complexities "manageable" for policy intervention.

Table 4 A framework for green innovation policies

Policy Style	Science/technology system			Intermediate system			Economic system
	Structure	Conduct	Performance	Structure	Conduct	Performance	Structure
Facilitating	• research funding	• fundamental long term research	• greening of knowledge	• network management • network money • Greening of NSI	• Supportive infrastructures	• rewarding green choices	• management o global competition • niche management • support of emerging gree markets
Initiating	• green sciences	• Privileging early green adapters	• Green knowledge "production"	• greening of network infrastructure	• discourse on green values and standards	• discourse on green of technology	• endogenous green transactions • convenants an agreements
Enforcing	• greening of teaching programs	• blocking research trajectories • withdrawal of research money	• blocking technologies and trajectories • conditioning new technological trajectories	• participation of green groups • access	• cooperation among firms and organizations	• sincerity of information • contractual relations	• legitimizing internalization of externalities

Fifthly, the table consistently broadens and widens the scope of innovation policies in comparison to the innovation programs currently dominating many policy arenas. These programs predominantly address the economic frame conditions, firms' conduct in the economic system and provide, at best, for additional services regarding cooperation between innovators and firms. In the perspective of evolutionary based green innovation policies the scope of these programs is far too limited to encourage real green technological transitions and the emergence of new green technological trajectories in the longer term. The results of the current innovation programs are rather incremental steps in greening technology and their diffusion potential sticks to the level of firms and branches.

Sixthly, Table 4 illustrates the need of combined strategies incorporating reinforcing logic, both in time and space. Green innovation policy should not be restricted to the short-term intervention of firm's activities and performances but they should also support and encourage the renewal and greening of the science/knowledge base in the longer term, to allow for the "endogenous" development and emergence of green technologies. Improvement and innovation of the intermediate system (techno-economic networks) in which innovation and technology is communicated, and technical and service needs are exchanged may support the emergence of such technologies. Therefore, green innovation policies have to be oriented on the short, medium and long-term simultaneously. In this way, strategies can reinforce each other to support "discontinuity" in the nestled structures and routines of the past, in order to contribute to the emergence of new, green technology. Drawing on evolutionary theory, only in this way, green technology itself will find its way through history by paving its own green paths.

5 Conclusions

This paper started from the observation that technological innovation is a necessary condition for handling environmental problems advanced economies are currently facing and to green technologies that can meet advanced environmental standards such as sustainability of socio-economic development. At the same time it was concluded that present innovation policies are hardly facilitating to induce these kinds of green innovations, among others, due to rather restricted cognitive maps underlying these policies. We then argued how evolutionary theory can be very helpful here, and that with the help of evolutionary concepts a more sophisticated understanding of the processes surrounding the emergence of technological variation and selection of specific technological options is possible. Innovation policies can be improved by drawing on these dynamics to stimulate the greening of present technological trajectories and the emergence of new green technological trajectories.

The suggested framework for designing green innovation policies builds on the complexities of socio-technical change processes in the economic system, the science/technology system as well as the devices mediating both systems. Technological change turned out to be embedded in highly institutionalized environments and driven by dynamic interplay of processes of variety (novelty creation) and selection, which constitute specific self reinforcing technological trajectories resulting in certain path dependencies over time. These dynamics are reflected in both the science/technology system and the economic system, and driven by a common logic. Following the theoretical inquiry in the dynamics of innovation, section 4 suggested an evolutionary-based framework for green innovation policies. It has been argued that the potential to increase the greenness of innovations depends on the potential to

simultaneously affect selection processes not only within the economic and the science/technology systems, but also at their interface - the intermediary system. This can be done by affecting the structure, conduct and performances in all three systems, and by using an appropriate policy style - facilitation, initiation, or enforcing -, at the right moment and the right place. The policy framework presented in this paper should be taken as a first attempt to improve present innovation policies and to design new, green, innovation policies. The framework reflects the need to arch innovation policies over time and space, in order to secure a wider reach and a more stable outcome of technological innovation and change. The lesson taught by evolutionary theory is that innovation is driven by an own logic and rationality. The challenge of greening innovations is to make use of this logic and rationality to bring the greenness of technology endogenously into the dynamics of socio-technological change.

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