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Systems of innovation: theory and policy for the demand side[1]

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Abstract

As an emerging current of thought in the economics of innovation, systems of innovation (SI) theorizing offers a non-linear perspective that is highly relevant to the formation of innovation policy. SI approaches are particularly appropriate to understanding the use of "demand side" policy instruments such as public technology procurement. In this article, we briefly summarize some general characteristics of SI approaches and relate them to broader theoretical developments in the economics of innovation. We explore one of the main characteristics of systems-oriented approaches to the study of innovation: the emphasis on interdependency and interactive learning. A number of theoretical antecedents to SI approaches are examined, and their main insights regarding the innovative role played by the demand side are elaborated. On this basis, some elements of a general policy perspective are identified.

Keywords: Economics; Innovation; Demand; Theory; Policy; Systems approaches; Antecedents; Evolutionary theory; Institutions; Interactive learning; Chains of Innovation; Sources of Innovation; User–producer interaction; Networks; Development blocks

1. Theoretical and policy perspectives on innovation

Innovation policies can be classified as *demand-side* oriented or *supply-side* oriented. Similarly, theories of the innovation process can be classified as being *linear*

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or *systems*-oriented. There are important parallels and logical connections to be drawn between these two classifications. On the one hand, linear views of the innovation process support a supply-side orientation in innovation policies. On the other hand, systems perspectives on innovation yield a much more fruitful perspective on the demand side, in terms of both theoretical and policy relevance.

1.1. Linear models of innovation

The so-called linear model of innovation has been generally accepted throughout much of the period since World War II [1]. A linear view of the innovation process means that "science leads to technology and technology satisfies market needs" [2]. It conceives of commercial research and development as applied science and envisions a smooth, uni-directional flow from basic scientific research to commercial applications. In this model there is no feedback from the several later stages of the innovation process (i.e., product development, production, and marketing) to the initial stage of research, nor is there feedback between any of the other stages.

The linear view is very simplistic (and, we would argue, unrealistic). Nevertheless, it has derived considerable legitimacy from being highly consistent with neo-classical economic theory's "market failure" explanations of the need for public support of industrial R&D, both directly (through subsidies) and indirectly (through funding of basic scientific research) [3,4]. However, in practical terms these theoretical formulations are not very helpful. They do not assist the development of specific innovation policies because they do not indicate the amount of government intervention required, the particular fields in which it is required, or the type of intervention required [5].

Problems with the linear model of innovation, including the complete absence of feedback paths that has already been noted, have been summarized by Kline and Rosenberg [1]. According to these authors, "the shortcomings and failures" that are "part of the learning process that creates innovation" mean that in both radical and incremental innovation "feedbacks and trials are essential" (p. 286). Another problem is the view of commercial R&D as applied science. Basic scientific research does not always lead to the design of innovations. Conversely, "problems that are thrown up by the processes of designing and testing new products and new processes often spawn research—true science—and have in some instances even given rise to new branches of mathematics" (pp. 286–287). Technological innovations may also proceed independently of any interaction with science, although other types of interactions might be important. These and other considerations support an alternative "chain-linked model" of the innovation process (p. 289). This model is characterized by a central path beginning with design rather than research and marked by multiple feedback loops.

1.2. Systems-oriented perspectives on innovation

This more systemic view of the innovation process explicitly recognizes the potentially complex interdependencies and possibilities for multiple kinds of interactions between the various elements of the innovation process. It is also evident from the example of the chain-linked model that a systems-oriented view of innovation accords great importance to the demand side, rather than concentrating primarily, if not exclusively, on the supply side. Such a perspective is essential to evaluating the role in public policies for innovation of demand-side instruments such as public technology procurement.[2] Public technology procurement is not only a matter of price signals and quantities anonymously sold and bought, but also involves interaction and learning processes that use other kinds of information. Thus, it is neither understood nor explained well by standard economic theory's supply-oriented market failure explanations of the need for government intervention in the innovation process, nor is it adequately represented by the associated linear model of innovation [9].

2. Systems of innovation approaches

A logical extension of systems-oriented theory and research in the economics of innovation has been the recent emergence of systems of innovation (SI) approaches [10–12]. SI theorizing includes non-linearity and interdependence, and it is therefore natural to emphasize the demand-side policy instruments in this approach. The emergence of SI approaches and their characteristics have been dealt with by Edquist [13]. Nine characteristics of SI approaches have been identified:

1. *They place innovation and learning processes at the center of focus*. This is based on the understanding that technological innovation is a matter of producing new knowledge or combining existing elements of knowledge in new ways. It is thus, in the broadest sense, a "learning process".
2. *They adopt a holistic and interdisciplinary perspective*. They are holistic in the sense that they try to encompass a wide array—or all—of the determinants of innovation that are important. They are interdisciplinary in the sense that they include not only economic factors but also organizational, social and political factors.
3. *They employ historical perspectives*. Since processes of innovation develop over time and include the influence of many factors and feedback processes, they are best studied in terms of the co-evolution of knowledge, innovation, organizations, and institutions.
4. *They stress the differences between systems, rather than the optimality of systems*. They make the differences between systems of innovation the main focus, rather than something to be abstracted away from. This means conducting comparisons between existing systems rather than between real systems and an ideal or optimal system.

[2] Public technology procurement occurs when a public agency places an order for a product or system which does not exist at the present time, but which could (probably) be developed within a reasonable period through additional or new technological development work, carried out in order to satisfy the demands of the buyer. Recent discussions of public technology procurement include Refs. [6–8].

5. *They emphasize interdependence and non-linearity*. This is based on the understanding that firms almost never innovate in isolation but interact more or less closely with other organizations through complex relations that are often characterized by reciprocity and feedback mechanisms in several loops. This interaction occurs in the context of established institutions such as laws, rules, regulations, norms, and cultural habits [14]. Innovations are not only determined by the elements of the systems, but also by the relations between them.
6. *They encompass product technologies and organizational innovations*. This is based on the understanding that developing a differentiated concept of innovation—one that is not solely restricted to the conventional emphasis on process innovations of a technical nature—is necessary to comprehend the complex relations between growth, employment, and innovation.
7. *They emphasize the central role of institutions*. They do so in order to understand the social patterning of innovative behaviour—its typically "path-dependent" character—and the role played by norms, rules, laws, etc. and by organizations.
8. *They are still associated with conceptual diffuseness*. Thus, further development will involve progressing from the present state of "conceptual pluralism" to a clearer specification of core concepts and their precise content—a gradual selection process in which pluralism and ambiguity will be reduced by degrees.
9. *They are conceptual frameworks rather than formal theories*. Recognizing that SI approaches are not yet at that stage of development where they are capable of formal (abstract) theorizing leads to an emphasis on empirically based "appreciative" theorizing. Such theorizing is intended to capture processes of innovation, their determinants, and some of their consequences (e.g., productivity growth and employment) in a meaningful way.

Conceptualizing systems of innovation as evolutionary systems in which institutions matter and learning processes are of central importance has significant implications for the development of corporate strategies and public policies [15]. In particular, SI approaches provide for a much more careful and detailed development of public policies for innovation than do variants of the linear approach discussed above. From an SI perspective, policy is partly a question of supporting interactions in a system that identify existing technical and economic opportunities or create new ones. The degree of innovation opportunity should be the deciding criterion in allocating support for certain types of interactions and hence for certain technologies and sectors. Moreover, the feasibility of alternative directions for innovation must also be evaluated, so that policy does not remain "blind" and support all alternatives in an indiscriminate way. Policymakers should develop selection criteria, such as the impacts on economic growth and employment, while supporting the creation of novelty. Thus, "Making these criteria explicit in terms of the economic and technical dimensions of innovation opportunities is a start toward informed decisions and policy-making" [15] (p. 220).

3. Origins of SI: interactive learning, evolutionary, and institutional theories

The development of SI approaches has been influenced by different theories of innovation such as interactive learning theories and evolutionary theories [13]. Later, we will discuss some antecedents that have focused especially on interdependencies between elements (organizations and institutions) influencing processes of innovation. However, we will first summarize the main theoretical origins of SI approaches, referring to some major works that represent key variants of SI theorizing. These include a sectoral or technological systems approach [16], and both “broad” [10] and “narrow” [11] versions of a national systems approach.

3.1. Interactive learning theories

Lundvall’s views exemplify the broad national approach which attempts explicitly to relate the national context to interactive learning theories of innovation [10]. In his book, contributing authors from Aalborg University in Denmark have integrated their own previously developed innovation theories within a conceptual framework of “national systems of innovation”. This framework stresses processes of learning and user–producer interaction. In Lundvall’s view, some kind of SI approach is arguably inherent in any perspective that sees the process of innovation as interactive [10] (p. 8). The notion of interaction paves the way for a systemic approach.

The focus on interaction within national systems also highlights the importance of institutions and organizations beyond the market. Several innovation theorists have convincingly argued that the model of the isolated, profit-maximizing firm is an inappropriate tool for interpreting certain important aspects of innovation processes. Many of the actors and organizations involved, such as governmental or private non-profit organizations, are not primarily governed by profit-seeking motivations. Legal conditions, rules, and norms will also significantly affect an organization’s inclination and possibility to innovate. Both non-profit and profit-oriented organizations, like firms, also interact with each other in complex ways when pursuing learning and innovation [17].

Authors who are working within the “interactive learning” tradition draw attention to how innovation processes, like most learning processes, are “influenced … by the institutional set-up of the economy” [18]. This analytical focus is informed by the view that, in concentrating its attention on the issue of responsiveness to price signals, mainstream economic theory has neglected the analysis of innovation as a process guided to a large extent by “responses to other signals and responses transmitted through other forms of social interaction than market exchange” [19].

3.2. Evolutionary theories

As an alternative to understanding technical change to be a result of seeking to maximize profits, Nelson and Winter propose that it can be understood as an evolutionary process [17,20–22]. An evolutionary theory of technical change often contains the following components:

- The point of departure is the existence and reproduction of entities like genotypes in biology or a certain setup of technologies and organizational forms in innovation studies.
- There are mechanisms that introduce novelties in the system, i.e., create diversity. These mechanisms include significant random elements but may also produce predictable novelties (e.g., purpose-oriented development work). In biology the novelties are mutations and in our context they are innovations.
- There are mechanisms that select among the entities present in the system. This increases the relative importance of some and diminishes that of others. The selection process reduces diversity and the mechanisms operating may be the natural selection of biology or either market selection or political-institutional selection as regards technical change. Together the selection mechanisms constitute a filtering system that functions in several stages and leads to a new setup of, for example, technologies and organizational forms. There might also be feedback from the selection to the generation of new innovations.

Nelson writes, "Technical change clearly is an evolutionary process; the innovation generator keeps on producing entities superior to those earlier in existence, and adjustment forces work slowly" [21] (p. 16). The technologies that are developed are only superior in a relative sense, not optimal in an absolute sense, and—contrary to standard economic theory—the system never reaches a state of equilibrium. Technological change is an open-ended and path-dependent process where no optimal solution to a technical problem can be identified.

Although the resource bases of various national systems strongly influence their patterns of innovation, technical change will likely also involve considerable randomness. In addition, the processes through which new technologies are screened, selected, and implemented take considerable time. Randomness, combined with the time-consuming nature of innovation processes, indicates that evolutionary models of technological change are a more realistic way of grasping and understanding innovations than the models provided in neo-classical economics [23].

Thus, evolutionary theory, in addition to interactive learning theory, is one of the theoretical perspectives that has strongly influenced the development of SI approaches.

3.3. Evolution, learning and institutions

Both evolutionary and interactive learning theories of technical innovation contain certain institutionalist perspectives that are absent from standard, or neo-classical, economic theory. There is an implicit institutionalist perspective in evolutionary theory's rejection of the isolated profit-maximizing firm as a primary focus in studying innovation processes. Institutions matter to this school of thought because it bases explanations of evolutionary patterns of change on the decisions and actions of agents in relation to institutions and organizations [24].

Despite the importance of these theoretical influences, they are not always overtly recognized in the main SI approaches. This is especially true in the case of evolutionary theory, which is not referred to in the narrow version of the national approach—this despite the prominence of Nelson as a leading contributor to both bodies of work.

There is no mention of evolutionary theory in Nelson and Rosenberg [25], and their version of the national approach is therefore not explicitly based in evolutionary theory. However, in his 1988 article on the US innovation system, Nelson argues that “in capitalist countries, technical change is set up as an evolutionary process” [26]. In his detailed survey of evolutionary theorizing [22], there are no indications that Nelson has abandoned the evolutionary perspective that he helped to establish [17,20]. Therefore, it seems safe to assume that the Nelson (and Rosenberg) version of an SI approach is implicitly based on an evolutionary theory of innovation.

The sectoral approach, exemplified by the work of Carlsson [16], is, however, explicitly based on an evolutionary perspective: “We have chosen an evolutionary approach because of its ability to bring within a single conceptual framework the institutional/organizational as well as the cognitive/cultural aspects of social and economic change” [27]. After this statement there follows a lengthy discussion of the role of creation of diversity and of selection mechanisms. In contrast, Lundvall does not refer to evolutionary theory in his introduction [10]. However, in chapter 4 of Lundvall’s book, Andersen explicitly discusses an evolutionary framework as well as the evolutionary foundations of learning by doing [28].

We have already shown that theories of interactive learning lie behind the Aalborg version of the national approach. We have also stressed the connection between theories of interactive learning and institutionalist perspectives [10]. And, we have indicated that evolutionary theories have a similar affinity with institutionalist perspectives. Furthermore, there might be an intimate relation between learning theories and evolutionary theories in the sense that learning is one mechanism through which diversity is created. Learning might even be an element in the processes of selection.

Carlsson and Stankiewicz, Nelson and Rosenberg, and Lundvall and his colleagues are all committed to the idea that technological change is an evolutionary process. Not only are SI approaches compatible with evolutionary theories but it could even be argued that there is a close affinity between them. This is also true of interactive learning theories. In addition, both evolutionary and interactive learning theories are connected, either implicitly or explicitly, with institutionalist perspectives. These connections appear to be strongest with respect to their common emphasis on the importance of non-market mechanisms for reproduction, the generation of diversity, and selection [14]. Hence, theories of interactive learning, together with evolutionary theories of technical change, constitute important origins of SI approaches and both are certainly compatible with them. So, too, are institutionalist perspectives.

4. Systems perspectives on interdependencies and interaction

Having described SI approaches in general terms, we can now proceed to a more detailed discussion of some important antecedents. We will concentrate on earlier systems perspectives on innovation in which interdependencies and interaction between users, producers, and other actors were considered to be of central importance. Some have already been mentioned. However, there is also a large body of work on so-called "innovation networks" that is relevant here [29]. In addition, theory and research on vertical integration and its relation to economic development [30] has strongly influenced SI approaches. For example, the concept of "development blocks" [31] has been used to understand the formation and development of different systems of innovation in Denmark and Sweden [32]. We will deal with several studies in turn, focusing on their main implications for SI perspectives.

4.1. Chain-linked model

We have already referred to the chain-linked model of innovation [1]. This model was developed primarily on the basis of historical studies of technological development [33,34] and contemporary studies of innovation management [35]. Apart from its emphasis on non-linearity, key features of this model were its strong emphasis on the crucial role played by the demand side in innovation processes and its closely related insistence that "Contrary to much common wisdom, the initiating step in most innovations is not research, but rather design" [1]. A bias toward product markets and product innovation was suggested by these terms of reference. A policy perspective was also implicit in these features of the model, although it was expressed in terms of "management of technology". Here, there was insistence on complementary strengths of different types of firms, and effective co-ordination among these and other actors as essential to creation and development of viable "innovation chains" for design, production, and marketing of new products—implying that government may have an important role to play, either directly or indirectly, in this capacity [1] (pp. 303–304).

This perspective is quite different from that of standard economic theory which, as the theoretical basis of linear models, has tended to neglect both product innovation and the structural character of interfirm relationships [28] (Section 4.5.1). The primary focus of mainstream economic theory has been on process improvements achieved through "learning by doing" in competitive markets where there are no fundamental differences among firms [36]. Relationships between buyers and sellers are here assumed to be so standardized that price signals are sufficient to convey all relevant information required by parties to any transaction [37]. In contrast to this orthodox view of an "extreme degree of flexibility" in systemic economic relationships, the chain-linked model prefigured SI approaches by devoting much greater attention to issues of "stability and 'linkage' structure" [28] (p. 82).

4.2. Distributed process model

The notion of chains of innovation was complemented by Von Hippel's theory of variation in sources of innovation [38]. This theory challenged long-standing assumptions that "product innovations are typically developed by product manufacturers" and replaced them with a model of a "distributed innovation process" in which product innovations could originate from any one (or combinations) of at least three distinct sources: suppliers, producers, and users [38] (pp. 3–5). Von Hippel held that sources of innovation would vary according to shares of "economic rents" that firms in each category could expect from a potential innovation [38] (Chap. 4). This successfully explained, for example, why major product innovations in fields such as scientific instruments are almost always developed by product users [38] (Chap. 2), and in contrast, why either product manufacturers or suppliers are developers of most important innovations in other fields [38] (Chap. 3). Firms' expectations of profits from innovation often have to do with relationships between categories of potential innovators and types of innovations being considered. In cases of process innovation, for instance, users can profit from secrecy, while manufacturers and others cannot [38] (Chap. 5).

In exploring effects of incentive structures on "distributed innovation processes", this theory pointed to non-rent-seeking practices of innovation such as "know-how trading". This occurs in industries where no one firm in a group of rivals possesses all the information required for innovation and none of them has sufficient incentive to develop a part of this information on an independent basis [38] (p. 90).

Finally, the theory identified strategies, such as the "lead user" concept, for "shifting sources of innovation". This meant altering normal patterns of interaction and information exchange among users and producers within a given product market so that the resulting modified incentive structure would induce more rapid and successful product innovation [38] (Chap. 8). In these respects, the distributed process model exhibited a definite systems orientation, made explicit in stating that "both innovation managers and government policymakers will find it useful to understand innovation behaviour at the systems level" [38] (p. 120). Important implications, particularly for policymakers, lay in discovering that the locus of product innovation can be shifted strategically by altering incentive structures and re-ordering relationships between users and producers.

4.3. Interactive learning theory

A third precursor of SI approaches, already mentioned, is the Aalborg school's [39] theorization of the learning dimension of user–producer interaction in product innovation [40]. The main point of departure was a critique of orthodox views of innovation as a process of "learning by doing" that (ideally) takes place within firms situated in perfectly competitive markets [36]. In such a world, "it should be obvious that perfect competition does not induce product innovation" [40]. Where all communication is through price signals, producers cannot acquire information about user needs not already served by markets. Conversely, users have no means of assessing new products, especially complex ones. Yet product innovation comprises the majority of important innovations, indicating ubiquity of (non-anonymous) user–producer relations [41]. Product innovation has to be explained by the existence of imperfect markets which meet "need(s) for qualitative information about new use-values used as inputs and about the needs of users" [40] (p. 69).

The argument thus far was essentially a case for vertical integration. If perfect competition militates against product innovation by restricting access to information about user needs, it would be logical for producers to integrate with users. This dynamic undermines anonymous markets and "gives rise to concentration both on the producer and the user side of the market" [40] (p. 20). However, creation of a market characterized by small numbers would result in unacceptably high levels of uncertainty and potential for opportunistic behaviour, since innovating units would have much better information about new products than potential users. Trends toward vertical integration would be further reinforced, and complete vertical integration would eventually reproduce the main effect of perfect competition: "All innovations should be in-house process innovations".[3]

For product innovation to occur, there must be limits to vertical integration. These arise from competitive needs for both users and producers to maintain broad access to information about product capabilities and user needs, respectively. The answer posed to this apparent paradox was that of "organized markets". This would involve consensual regulation of economic exchanges between users and producers. By restricting cheating and rewarding trustworthiness it would increase flows of information via stable relationships between users and producers. The quality of such information, moreover, would be improved through coordinating mechanisms such as user associations. Thereby, markets could be rendered non-anonymous but would simultaneously avoid the pitfalls of complete vertical integration: "This vertical 'semi-integration'…is a more easily reversed relationship that will not have as strong a negative impact on the flow of information as full integration" [40] (p. 28). Ideally, organized markets allowed for existence of elements of hierarchy, but demanded coexistence with these of countervailing elements of cooperation—"mutual trust and responsibility" [40] (p. 29).

Later work brought learning in organized markets into clearer focus [39]. The theory expected that markets where products were complex and changing rapidly would have high requirements for direct cooperation and exchange of qualitative information, leading users and producers to establish specialized channels and codes of information. This agreed with well-established economic principles of information [42] and organizational research on innovation [43,44]. It also captured the dimension of "cognitive structure", anticipating organizational theory's concept of "absorptive capacity" [45]. A major concern of interactive learning theory was that established "knowledge structures", originally necessary for innovation, could later become sources of inertia and resistance to change [39] (p. 355). Such problems would be especially pronounced when emergence of a new technological paradigm [46] made old codes incapable of communicating information about new areas of innovative activity [39] (pp. 355–356).

Interactive learning theory identified various unsatisfactory innovations based on established forms of user–producer interaction. These were usually cases of producer-dominated innovative activity deviating from user needs in both consumer [47] and industrial markets [48]. Correction of such cases called for a pooling of competence by users, possibly reinforced by government regulation or support for user organiza-

[3] This argument, it should be noted, would only apply to industrial markets. There would still be atomized consumer markets in which product innovation could occur [40] (p. 68).

tions. In some historical instances, however, users' commitment to existing user–producer networks, and their resulting resistance to formation of linkages with producers of emerging technologies, could lead to much broader economic problems of "mismatch" and reduced productivity that could not be resolved simply by strengthening conservative users [49]. Therefore, interactive learning theory placed "emphasis more upon the *quality of demand*, than upon demand as a quantitative variable" [39] (p. 357).

Interactive learning theory considered "lack of competence by users" and producer domination of innovation to be "as serious a problem as the lack of competence on the producer side" [39] (p. 358). It further considered that government could intervene "in relation to the establishment and restructuring of user–producer relationships" [39] (p. 358). In periods of gradual change, for example, government could either sustain existing linkages or reorder them. Finally, it considered that in periods of radical technological change, government might need to transform many of the established user–producer relationships that were supported by vested interests. "The difficult task for government will be to stimulate the renewal, or severance, of well-established user–producer relationships and the establishment of new relationships" [39] (p. 358).

4.4. Network analysis

Interactive learning theory's strong emphasis on institutional analysis led to the identification of a broad realm of economic relationships and innovative activities that belonged to "neither market nor hierarchy". This, in turn, allowed for another important influence on SI approaches—namely, emerging theory and research on networks of innovators [29]. There is now a voluminous literature on networks as a special form of economic organization between markets and hierarchies [50–52], and much of this work has dealt in various ways with themes such as learning and innovation [53–55]. In particular, Håkansson's work on industrial networks [56] has been cited as an important influence on SI approaches [16,57]. Due to its interest in studying patterns of linkage structure among firms and other organizations within fragmented markets, a major theme in this exploration of industrial networks devoted to collaborative development of new technologies has been the investigation of vertical and horizontal relations within networks.

In this approach, it is recognized that all user–producer (or customer-supplier) relations constituting inter-firm *networks* must, by definition, involve some degree of vertical integration (although, by definition, vertical integration can never be complete in an *inter-firm* network). Therefore, "horizontal" is used to describe networks based on other kinds of relations—including, for example, "co-operation between rivals" or "informal know-how trading" discussed by von Hippel [38]. This usage has generated a basic distinction between "trade" networks with a strong vertical aspect and "knowledge" networks with a strong horizontal aspect [57] (p. 120). Using this frame of reference, network analysis has demonstrated that product innovation in fragmented markets is associated with a drive toward consolidation of buying power and demand articulation by users, leading to tendencies toward vertical integration. Håkansson's research [56] has suggested that horizontal development relationships formed primarily for product innovation, are intended to develop both new markets and new vertical development relationships (user–producer relations) [58].

Market creation, that is, developing organized markets, is thus a major concern of networks formed around technological innovations within fragmented market settings. Teubal, Yinnon and Zuscovitch's work on network analysis addresses relationships between networks and market creation, with particular reference to "user–producer relationships characterizing many emerging capital-goods markets" [59]. In their argument, an entrepreneur, embodied in a focal organization, is considered essential to market creation. While collective learning often depends on networks, networks without focal organizations are likely to remain in "a low level equilibrium trap" [59] (p. 387). An organized articulation of demand is required to resolve coordination problems involved in market creation. Concentrated demand exercised by an entrepreneurial focal organization is equivalent to formation of a core of innovative users sufficiently large to dissolve the "trap". This argument connects Lundvallian "organized markets", discussed above, with Schumpeterian notions of entrepreneurship.

4.5. Development block theory

To overcome barriers to communication between producers of emerging products and a sufficiently broad range of potential users, the focal organization envisioned in network analysis requires extraordinary capabilities, particularly with respect to co-ordination and scope of R&D in a new market environment where opportunities for expansion of sales through gathering and diffusion of relevant information can be extremely difficult [59]. Thus, the Schumpeterian concept of a "collective entrepreneur" is introduced as the *sine qua non* of successful innovation processes. In order to innovate, the entrepreneur—often "a major business firm" in the case of complex technologies requiring extensive resource mobilization—"has to perceive the (future) need, identify the necessary ingredients, secure the resources that may be missing initially, and communicate … vision to the relevant agents—capitalists, suppliers of raw materials, people with the required skills, etc." [27] (pp. 40–41). These insights, central to most SI approaches were originally expounded in the systems-oriented theory of "development blocks", pioneered by Swedish economic historian Erik Dahmén in work first published in 1950 and later elaborated by many others [28,31,32,60].

A special emphasis of development block theory is that needs for linkage and coordination arise out of structural economic tensions emanating from gaps in technological development [61]. These are indicated, not only by price and cost signals but also by other forms of communication among actors in economic networks. "In both cases, the challenge is in 'gap filling' which tends to eliminate structural tensions but may also lead to new tensions by overshooting, as technical and other solutions sometimes run ahead of the immediate goal" [61] (p. 6). For innovation, then, a continuing drive toward increased market power vis à vis producers by a "focal entrepreneur" representing diverse user needs is justified, perhaps demanded, so long as the core technology's development potential has not been exhausted. However, when "development blocks have reached a state of saturation and, perhaps, overaccumulation" entrenched entrepreneurs become candidates for "forced adaptation or creative destruction".[4]

5. Conclusion: some general policy implications of SI approaches

We have reviewed various theoretical aspects of SI approaches, concentrating on their relevance to understanding innovation. Our discussion of their origins in theories of interactive learning, evolutionary theories, and institutional perspectives has shown that SI approaches are especially capable of understanding non-linear development of knowledge based on exchanges of information among interdependent actors. Subsequently, we have examined some antecedents of SI approaches, with a view to outlining some general policy implications. From stating broadly that systems approaches, compared to linear conceptions of innovation, have a superior grasp of demand-side issues, we have proceeded to a more detailed examination of specific insights into the dynamics of product innovation and its organizational requirements. This theoretical legacy, combining different but complementary theoretical views on interdependency and user–producer interaction, makes SI approaches particularly useful for understanding demand side innovation policy instruments, such as public technology procurement.

We can now briefly summarize some main policy implications. Each antecedent of SI approaches considered above is associated with particular policy implications. However, these policy implications can also be taken as complementary components of a broader SI policy perspective—much as the various "appreciative" theories and models with which they were originally associated have since been incorporated into a broader set of theoretical perspectives on systems of innovation. What follows then, is a brief outline of certain elements of an SI policy perspective.

The *chain-linked model* placed a strong emphasis on the demand side's crucial role in innovation processes and focused mainly on product markets and product innovation. It stressed that management of innovation (including public policy) should recognize complementary strengths of different types of firms and seek to coordinate their efforts through creation of viable "chains of innovation" involving linkage structures among firms and other actors.

The *distributed process model* identified different potential sources of innovation and revealed that product innovation does not always reside with product manufacturers. Instead, it is moveable and can be strategically shifted by altering incentive structures. This can be done, for example, by adopting lead user strategies. Such strategies can have direct applications in public technology procurement. Alterna-

[4] For a more comprehensive account of an SI perspective on current issues and priorities, on both the demand and supply sides, in innovation policy, see Ref. [62].

tively, they can be promoted indirectly. Both approaches depend on modification of existing incentive structures, and both imply a restructuring of relationships between users and producers.

Interactive learning theory advanced a policy perspective that was based on learning through user–producer interaction in organized markets. This perspective placed greater emphasis on *quality* of demand than upon its simple quantity as a basis for strategic intervention in innovation processes. It pointed to producers' domination of innovation processes as a fundamental problem and argued for public intervention to restructure user–producer relationships, suggesting that in periods of rapid technological change governments may have to overcome inertia based on vested interests. The theory pointed to governmental responsibilities for making organized markets conducive to innovation

Network analysis pointed to dynamic tension between vertical integration and horizontal collaboration among organizations in the creation of new product markets. Some analysts argued that a focal organization providing vertical linkage between users and producers is often necessary to overcome a "low-level equilibrium trap" facing networks formed around emergent technologies. Especially where further development of a given technology could be shown to have beneficial consequences for economic welfare, a case could be made for involvement of public agencies in market creation. This would involve an organization or articulation of demand resulting in, or equivalent to, formation of a core of innovative users sufficiently large to overcome problems of otherwise inadequate critical mass.

Development block theory highlighted innovation-induced structural tensions giving rise to formation of a broad set of interconnected producers and users of products, developing interactively, often aided by knowledge-producing organizations. A development block is a large-scale framework for interactive learning. Development blocks differ from networks per se primarily in that they can successfully overcome problems of critical mass. Development block analysis enables policy makers to discern and evaluate transformation problems between user needs and production characteristics occurring in early development of new technologies. Policy may also have to fill such gaps in a way that will both stabilize situations and open up new possibilities for development. Public agencies may have to play this role where no "natural" entrepreneur is present—especially where technologies are extremely complex and demands for resources and influence are large.

These elements by no means describe an all-encompassing SI policy perspective on the demand side, just as the various theories from which they have been drawn do not address all aspects of the demand side of innovation. (For example, they do not capture all aspects of standard setting and product market regulation—topics not addressed here.) However, clear complementarities between them indicate how they can be used, within an SI framework, as essential means for the development of demand-side policies for innovation. Despite historical neglect of the demand side, especially in standard economic analyses of innovation, such policies remain important and now appear to be gaining greater practical significance in economic policy making.

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