National Systems of Innovation

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Summary and Keywords

The pursuit of economic growth stands out as one of the main imperatives within modern economies. Nevertheless, economies differ considerably in their competitiveness. Theories on the endogeneity of growth agree on the value of knowledge creation and innovativeness to determine a country's capability to achieve a sustained performance and to adapt to the dynamics of changing environments and faster information flows. To this effect, national institutional regimes shape nation-specific contexts and embed individuals and firms. The resulting incentive structures shape the attitudes and behavior of individuals and firms alike, whose interactions contribute to the accumulation and flow of knowledge among the nodes of their networks. National systems of innovation (NSIs) therefore embody a concept that aims to analyze the national innovation performance of economies. It rests its rationale in the variation of national institutions that shape the diffusion of technologies through the process of shared knowledge creation and the development of learning routines. Both public and private institutions are thought to interact in a given nation-specific institutional context that essentially affects incentive schemes and resource allocation of the involved economic agents in creating, sharing, distributing, absorbing, and commercializing knowledge. To this effect, public policy plays a key role in the NSI through building bridges between these actors, reducing information asymmetries, and providing them with resources from others within the system. The different actors contributing to the creation and diffusion of knowledge within the system are needed to exchange information and provide the engine for sustained economic growth. Universities, research institutes, companies and the individual entrepreneur are in charge of shaping their economic system in a way that resource and skill complementarities are exploited to the mutual benefit.

Keywords: innovation, technology, knowledge, institutional context, systems theory, innovation policy

National Systems of Innovation as a Field of Research

Economists are eager to understand how economic growth and prosperity can be stimulated in the best ways possible (Lucas, 1988; Romer, 1990). Commonly, a consensus has been attained that the endogeneity of growth is determined by the amount and type of knowledge accumulation that aims at boosting a nation's innovation output. To this effect, investments through public policy in the societal skill base are needed to build up a knowledge accumulation that supports the technological function of the economy in a complementary manner (Acs, 2006; Acs, Audretsch, Braunerhjelm, & Carlsson, 2012; Acs & Szerb, 2007; Audretsch, 2006; Freeman, 2002; Verspagen, 2005). One of the various approaches within literature to analyze the innovation-based endogeneity of growth (Antonelli, 2015, 2019; Braunerhjelm, 2019) is the notion of the national systems of innovation. This approach focuses on national innovation patterns and explains how national economies differentiate according to their innovation type and intensity. This article first introduces this approach and its "DEFINITION AND INTENT" and then, in "ORIGIN AND CONTEXT," goes on to describe the origin of the research field and place it in the literary context. "DIMENSIONS OF AN NSI" focuses on four selected aspects of the NSI that have received particular attention within literature: First, the article explains which key "INSTITUTIONS AND ACTORS" shape the innovation framework of a country, and then what type of "KNOWLEDGE FLOWS" achieve to stimulate the innovation output. "'SYSTEMS' IN NSIS: SOCIAL, OPEN, OR CLOSED" examines the concept of systems in NSIs in more detail, and "NEED FOR ACTIVE GOVERNANCE" addresses the important role of public policy and points out why NSIs need to be proactively governed.

Definition and Intent

To begin, a first understanding of NSIs is derived through analyzing the various definitions literature so far has emulated. Freeman (1987) and Nelson (1993) focus on institutions and define an NSI as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (Freeman, 1987, p. 1) and as "a set of institutions whose interactions determine the innovative performance of national firms" (Nelson, 1993, p. 4); others, such as Patel and Pavitt (1994, p. 12), emphasize the importance of technological learning and state that an NSI describes "the national institutions, their incentive structures and their competencies, that determine the rate and direction of technological learning (or the volume and composition of change generating activities) in a country." Yet Lundvall, Vang, Joseph, and Chaminade (2009, p. 7) emphasize the systemic dimension of NSIs and argue that an NSI describes "an open, evolving and complex system that encompasses relationships within and between organizations, institutions and socio-economic structures which determine the rate and direction of innovation and competence-building emanating from processes of science-based and experience-based learning."

Although the concept of an NSI is quite recent, it is rooted in earlier concepts pushing the state and the government against the free-trade doctrine, with Friedrich List as a predecessor of this concept. The modern roots date back to Freeman (1987), Lundvall (1985), and Nelson (1993), which were critical to recent public policy inspired by standard neoclassical economics, pointing to alternative policy descriptions. These scholars, who gave birth to the concept, challenge the neoclassical model based on equilibrium analysis and rational expectations offering a satisfactory explanation on economic growth and international competitiveness. By introducing NSIs, these authors try to offer an alternative explanation of why growth rates differ and how countries can build competitive advantages based on structural competitiveness.

From a theoretical point of view, the concept of NSIs replaces the static economic equilibrium theory and the linear model of innovation where investments in science automatically result in innovation and economic growth by an evolutionary and dynamic perspective. Instead of relying on a dominating push-and-pull perspective, the concept of NSIs provides a framework that inspires scholars to study innovation by emphasizing the role of networking and interaction. This renders the analysis to a systemic perspective where context matters even more, encompassing all the relations within and between organizations, institutions, and socioeconomic structures (Chaminade, Lundvall, & Hansef, 2018). All of the scholars who gave birth to the concept of NSIs shared the same view on the systematic and dynamic perspective, but their proposed concepts differ between narrow and broad definitions of NSIs, reflecting different theoretical and political perspectives.

Nelson suggested a narrow definition focusing on the interaction between existing firms and research institutions. His analysis relied on a microeconomic perspective on innovation, building on Neo-Schumpeterian economists (Nelson & Winter, 1982) and based on bounded rational agents and on tacit rather than codified knowledge, with an emphasis on the process of search and exploration. Broader definitions are proposed by Lundvall and Freeman, among others, including social interactions and learning processes also taking place inside firms regarding the innovation process beyond the special attention to almost radical innovation and emerging technologies, but also to the diffusion and use of new technologies (Chaminade et al., 2018).

As Filippetti and Archibugi (2011, p. 180) put it, the concept of NSIs builds on the following assumptions: (a) “that countries exhibit systematic differences in terms of economic performance; (b) that economic performance depends in large not only on different technological and innovation capabilities, but also on the development of institutions; and (c) that innovation and technology policies are an effective tool for fostering and shaping the performance of countries.”

NSIs are characterized by the plenitude of institutions inherent in national economies, such as research institutions, financial intermediaries, school and universities etc. Basically, everything that helps to create and diffuse knowledge is targeted by the NSI framework to improve smooth interactions and the exchange of information (Fagerberg & Srholec, 2009; Hall & Soskice, 2001; Lehmann & Seitz, 2017). As the assumptions of Filip-

petti and Archibugi state, the differences between countries in their ability to stimulate economic performance through their innovative capacity rest on differences that emerge on the national level. This perspective implies that “geography is fundamental, not incidental, to the innovation process itself: that one simply cannot understand innovation properly if one does not appreciate the central role of spatial proximity and concentration in this process,” as Asheim and Gertler (2004, p. 292) point out. Economic activities increasingly are determined by the role of geographic proximity as knowledge exchange and spillovers both contribute to foster innovation (Acs, Audretsch, & Lehmann, 2013; Audretsch, Keilbach, & Lehman, 2005; Braunerhjelm, Acs, Audretsch, & Carlsson, 2010; Ghio, Guerini, Lehmann, & Rossi-Lamastra, 2015). Spatial proximity here refers to the situation for when an object, such as a firm, happens to locate nearby another object, such as an agglomeration of other organizations or individuals (Aguilera, Lethiais, & Rallet, 2015). This is key to the emergence of knowledge spillovers, which are defined as

> “the unintentional transmission of knowledge to others beyond the intended boundary. At every possible interaction, there is a potential for knowledge exchange. If knowledge is exchanged with the intended people or organizations, it is ‘knowledge transfer,’ any knowledge that is exchanged outside the intended boundary is spillover.”
>
> (Fallah & Ibrahim, 2004, p. 8)

Still, the latter leaves out to discuss and incorporate the concept of institutions as the rules of the innovation game. It is essential to acknowledge that these rules are predominantly fixed on the national level, where national legislations are set. The capacity for innovation thus is not disseminated evenly between countries, which is why NSI use the country as level of analysis (Freeman, 2002). Literature revolving around NSI describes that insights and outcomes sometimes were seen as counting for countries in general and just alike. In fact, these countries differ with regard to their institutional arrangements, what refers to culture, the nature of their industry, research institutes, the technological learning curve and implementation of innovation policies (Audretsch, Lehmann, Richardson, & Vismara, 2015).

Origin and Literature Context

While List (1841) laid the early foundations, the actual framework of national systems of innovation (NSIs) has been established through the work of Lundvall (1992) and Nelson (1993). The concept aims at unraveling the nature of innovative activities and the interaction of organizations and the institutional context they are embedded with (Acs, Autio, & Szerb, 2014; Edquist & Lundvall, 1993; Filippetti & Archibugi, 2011; Leyden, 2016; Leyden & Link, 2015A, 2015B). This insights helps to understand why nations produce different results in their innovation output, as its economic agents are incentivized according to the differing national institutions and the availability of resources and capital (Lundvall, 1992; Nelson, 1993). The field since then has been established sustainably over the years. This is reflected in Figures 1 and 2, which show the number of articles since 1990

that either use the words “national system of innovation” within their title (Figure 1) or use keywords within the text (Figure 2).

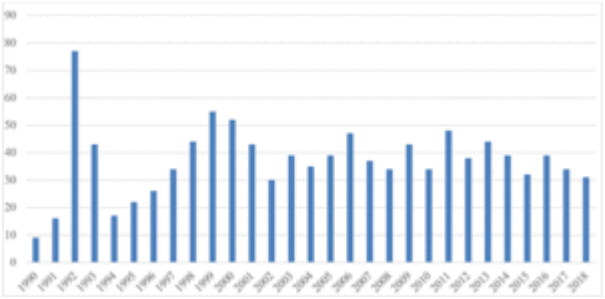

Figure 1. Number of articles that have “NSI” within the title.

Source: Own depiction.

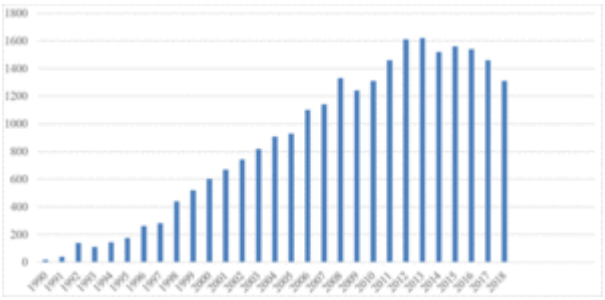

Figure 2. Number of articles that have “NSI” somewhere within the text.

Source: Own depiction.

Reviewing literature on growth regimes and economic performance reveals that notions like “technological regimes,” or “technological systems” and “accumulation regimes,” have already applied a similar lens as that used by the field of national systems of innovation (Antonelli, 2019).

All of these notions share the basic intuition that the generation of technological knowledge and the introduction of innovations are determined by the intertwined nature of the structure, organization, technology, and knowledge governance at the systems level, with major effects on upward and downward complementarities (Antonelli, 2015, 2019; Dopfer, Potts, & Pyka, 2017). Although “technology regimes” in general are defined exclusively by the industry-specific characteristics of the technological environment in which innovative activities take place (Castellacci & Zheng, 2010), the notion of “accumulation regimes ” is far richer and also pays attention to the financial system and other mechanisms providing resources to innovation in general, in addition to encompassing the level of openness of economic systems to international trade and international financial markets (Antonelli, 2019, p. 7).

The national systems of innovation approach lies between the technology regimes and the accumulation regimes approaches. It extends the scope of analysis of the technology regimes approach with a systematic analysis of the mechanisms and channels of knowledge interactions put in place at the national level. The national systems of innovation approach thus complements the technological regimes approach focusing on the systemic interactions and complementarities in the generation of knowledge and the introduction of innovations at the national level (Antonelli, 2019, p. 6). Although the national systems of innovation approach is focused on the determinants of the introduction of innovations, it abstracts from the macroeconomic performance of the system, which lies in the focus of the accumulation regime approach. With a focus on the national level, the national systems of innovation approach clearly involves governance structures on the national level —the role of politics to shape the mechanisms and channels of knowledge interactions (Antonelli & Link, 2014).

Early academic research on NSIs was mainly concerned about setting the standard, by introducing the new framework, offering definitions and explanations as well as qualitative analysis, or suggesting research agendas. This is reflected by the large number of articles with “NSI” in the title. Starting with a small number of publications in 1990 that deal explicitly with the NSI, as expressed in the title, the highest peak in the number of publications was reached immediately after the introduction of the concept, namely, in 1992. Then the number of publications declined until reaching a new peak in 1999. This decade is best described by Joseph Stiglitz (2004) in his famous book *The Roaring Nineties*, where the national systems of innovation in the United States were the driving force of a prosperous decade and became the leading role model for innovation policies around the globe. After the dotcom crises in 2001, the interest in titles with “NSI” declined, but even after the euphoria of this new framework and the decade of the national system of innovation, key lessons, insights, and takeaways about the forces coming from innovation as the driver of economic prosperity and success were not lost, reflected by a lower level of publications until 2011–2012. Since then, the interest in publications with “NSI” in the title shrank from about 40 publications a year, to about 30. Despite the publication lag (publications from more recent years are slightly underrepresented because some publications are in the referee process, in the production of publishers, or still in existence as working papers), also frameworks and concepts have to follow the ups and downs of a life cycle. In the past decade, new frameworks have entered the landscape, focusing instead on the effect of innovation on entrepreneurship and shifting the geographic boundary toward the regional and urban levels. Concepts and frameworks like the national system of entrepreneurship entered the academic landscape (see Acs et al., 2014), replacing the focus on innovation with the lens on entrepreneurship as the main driver of exploiting and exploring new ideas and innovations. The concept of geographic boundaries has shifted from the national level toward a new approach, the ecosystem (Acs, Stam, Audretsch, & O’Connor, 2017B; Nambisan & Baron, 2013; Stam & Spigel, 2017; Terjesen et al., 2017; Zahra & Nambisan, 2011). Both concepts, the entrepreneurship framework and the ecosystem approach, have led to an extension of publications focusing on NSIs as expressed by the title of the respective publications.

Although the topic of titles may change over time for several reasons, the lessons, insights, and takeaways remain the same in explaining the relationships among innovation, competitiveness, and economic performance. Just because the “ingredients”—like ideas, innovation, public policy, exploitation, and exploration of ideas and the sources of knowledge—may shuffle in their composition, big companies, universities, research labs or new ventures, and entrepreneurial firms still remain the same. This is best reflected by analyzing how often the expression “NSI” appears in keywords (see Figure 2).

After the first publications on NSIs, the number of articles drawing on this concept drastically increased within the next two decades, with a peak in the years 2011–2012 when more than 1,600 publications emerged within this field of interest. With over 1,000 publications a year, the NSI is still a main topic in academia and will continue to be in the future.

Although the NSI literature is mainly based on and rooted in the Schumpeterian tradition and dynamics, the NSI approach almost abstracts from one important agent, the entrepreneur as an agent of introducing radical innovations and creative disruption. Much of a country’s innovation and technological progress was driven by large corporations until the end of the 1980s and the beginning of the 1990s, but this has since changed. With the emergence of high-technology clusters, in particular Silicon Valley in the United States, the Research Triangle in North Carolina, and Route 128 in Massachusetts, the omission of entrepreneurs as the main economic agents in exploiting innovations, in combination with the focus on inherited structures, has given the NSI approach quite a static flavor in the literature. This led to the emergence of the national systems of entrepreneurship approach (Acs et al., 2014), where individual decision-making, in particular from entrepreneurial agents, gives rise to an individual-centric perspective without neglecting the institutional context. This approach has been used as a substitute framework in explaining performance on the country level, implying that systems performance can be held back by entrepreneurship as a bottleneck factor (Acs et al., 2014, p. 476).

Dimensions of NSIs

As stated previously, some topics have proven to be particularly prominent in the research on NSIs. These fields of research are presented in more depth “INSTITUTIONS AND ACTORS,” “KNOWLEDGE FLOWS,” and “‘SYSTEMS’ IN NSIS: SOCIAL, OPEN, OR CLOSED.”

Institutions and Actors

Countries differ in their set of national institutions, which must be coordinated to enable such interaction. This, in turn, supports the diffusion of knowledge and technology in the best possible way. This is an essential insight into how the diversity and complementarity of national institutions and their interaction explains why countries differ with regard to the amount and type of innovation they produce. Roberts analyzes the interaction of choice and context variables, whereby complementarity exists when “doing more of one

of them increases the returns to doing more of the other" (Milgrom & Roberts, 1995; Roberts, 2004, p. 34). Thus, according to Roberts, suitable combinations of context and choice variables can trigger systemic effects so that their value is greater as soon as they occur simultaneously and complementarily, creating more value than they would in isolated consideration. Context variables describe the institutional environment that can trigger or influence the change of an associated choice variable. Context variables reflect the institutional context actors are surrounded with, and examples include the tax environment (Carney, Gedajlovic, & Strike, 2014), the legal origin of a country and therewith the related availability of financial capital (La Porta, Lopez-de-Silanes, Shleifer, & Vishny, 1998), the educational system (Lehmann, Schenkenhofer, & Wirsching, 2019), business regulations (Van Stel, Storey, & Thurik, 2007), and so on. The latter examples range among the most studied institutional determinants of business activity.

Choice variables can be understood as control levers of policy makers, managers, or other authorities who endogenously stimulate the sign and magnitude of a strategic thrust. Therefore, there is expressly no one-size-fits-all solution—rather, depending on the exogenous context, decision-makers' choice variables must be changed in such a way that the overall welfare of all involved parties is increased in a pareto-efficient way. The decisive factor is complementarity, that is, the efficient interaction of participating institutions in the system, in order to advance technology accumulation. A good example of the importance of institutional complementarities is the way politics deals with a country's sectoral change. All Western industrial nations have witnessed the disappearance of the agricultural sector triggered by the Industrial Revolution. The three leading sectors of German industrialization, mechanical engineering, electrical engineering, and chemistry, were mainly driven by groundbreaking research and development (Audretsch & Lehmann, 2016; Audretsch, Lehmann, & Schenkenhofer, 2018) and could only replace the agricultural sector through a radical change of education and training systems to provide industry with skilled labor. The progress of a nation thus depends largely on how a country's public policy manages change and strategically builds and depletes resources to meet the needs of the economy, or how Lehmann et al. (2019, p. 5) put it: "In a technologically advanced economy, the societal skill base curve must stay parallel to and head of the technological implementation curve."

Following Patel and Pavitt (1994), four institutions in particular are recognized as central to national systems of innovation: business firms, universities, a mixture of private and public institutions, and the government. As these institutions are organizations that a society imposes on itself, the structure of these organizations shapes the incentives and thus interactions of political, economic, and social actors (Edquist & Johnson, 1997; Glaeser, La Porta, Lopez-de-Silanes, & Shleifer, 2004; Hodgson, 1988; North, 1991). Lundvall (1998, p. 409) instead takes a different perspective on the shape of those institutions in relation to NSIs. For him, institutions affect learning activities and therefore a nation's innovativeness through (a) the time horizon of agents, (b) the role of trust, (c) the actual mix of rationality, and (d) the way authority is expressed. These various facets of the institutions are presented in the following.

The time horizon of agents has a major impact on investment strategies and the type and amount of available financial capital, as Japan or Germany traditionally are economies deploying rather long-term investments, whereas Anglo-American economies are keen on more short-term horizons. Certain types of firms and types of innovations rely on short-term time horizons and more liquid capital markets, whereas others might rather benefit from long-term investments, for example, those carried out in close relationships to banks or institutional investors.

The second institution Lundvall (1998) puts forward revolves around the role of trust, which he describes as “mutual expectations regarding consistency in behavior and full, truthful revelation of relevant information and loyalty in difficult times” (Lundvall, 1998, p. 410). Trust is essential to limit transaction costs and to catalyze the extent to which agents can participate and thrive within interactive learning and innovation. Especially, innovation processes involve a great deal of risk and patience, and therefore the incentive to contract is highly influenced by the amount of trust being shared among the involved agents.

The third institution refers to the rationality of economic agents. Here, Lundvall points out that next to instrumental rationality, agents exhibit a communicative rationality that comprises a common understanding that is attained throughout the process of working together for a common goal. The individual utility, and therefore its underlying rationality to pursue a certain aim, is derived especially throughout the discourse rather than solely in the final result. Learning as a highly interactive process, therefore, would be impossible if one is to assume that individuals only process information and decide for a certain behavior whenever their entire rationality would be solely derived as a single and isolated exchange act, which would then equal a sole instrumental rationality.

Finally, interactive learning is influenced by the degree and type of authority inherent within industrial relations. When agents learn new skills, this usually will “take place in the context of a master apprenticeship relationship where a mixture of trust and authority is necessary if learning should be efficient” (Lundvall, 1998, p. 410). The nature of the distinct authority differs nationally from system to system. According to Lundvall, societies that are more traditional place a greater role on age and seniority that guide many of the learning routines, whereas other societies replace this with financial resource allocation.

It is important here to point out that a linear model of innovation is not the best lens to reflect the versatility and dynamics of the innovation process, in which a large number of actors are involved. The linear model of innovation posits that innovation is initiated from science, and efforts in research will directly stimulate innovation (Godin, 2006; Kline & Rosenberg, 2010). The NSI view instead emphasizes that the national capacity for innovation results from the interaction of all actors in the system. This means that the relationship and cooperation of the nodes in the network are decisive for the flow of different tacit resources, such as knowledge, information, and experience. The system consists of a multitude of actors with their own incentive schemes. Universities generate new knowl-

edge through basic research and pass it on directly to students through their courses. Moreover, universities often cooperate with companies and contribute to the commercialization of knowledge either as an independent unit or in the form of collaborations with companies. In the case of public institutions, risks are borne by the state, which in turn affects investment horizons and the willingness to assume risk. Companies, on the other hand, bear the risk of their investments in research and development (R&D) in order to generate new knowledge. The generation of knowledge is much more specific and limited to the needs of the company's product range. Similarly, the employees of companies are trained specifically and therefore build specific human capital, which creates a mutual lock-in effect (Lehmann et al., 2019). Customers feed information into the system about their product demand. They transmit knowledge about usability, current relevance, and consumer trends. Companies also receive direct feedback from product evaluations, which can be decisive for the further development of the product range. Finally, suppliers present another example to this effect, as they act as a technological interface and exchange information directly with the producer on technology development and process integration.

Knowledge Flows

The second main topic, which has been discussed thoroughly within the field of NSIs, revolves around the knowledge flows inherent in NSIs, which lie at the heart of the NSI approach and have gained significance in the face of the technological change toward the knowledge society (Drucker, 1969). Although private investments in this knowledge base mainly concern the R&D efforts of private companies and privately owned research institutes, the state can leverage certain R&D investments and support open innovation networks. The research field of NSIs is concerned with all knowledge flows in national systems, that is, between the various actors involved, including identifying levers to improve the efficiency of the knowledge flow. Here, how knowledge flows across countries and between different national systems to create added value is important. Generally, certain subtypes of knowledge flows can be distinguished: (a) interactions among enterprises, (b) interactions within enterprises, (c) universities and public research institutes, (d) diffusion of knowledge and technology to enterprises, and (e) personnel mobility (Organisation for Economic Co-operation and Development [OECD], 1997).

What is critical is not only the acquisition of knowledge but also how it diffuses in society and among actors (Freeman, 1995). Also, for this reason a systemic perspective is appropriate to describe the interactions as fixed network ties that communicate with each other. On the one hand, it is crucial how much knowledge is fed into the system by all knowledge producers. On the other hand, the role of companies stands out to absorb this knowledge and combine it with their own knowledge for commercialization. Thus, the absorptive capacity describes the ability of a company to acquire knowledge sources and to evaluate, assimilate, and finally generate marketable innovations from this external knowledge (Cohen & Levinthal, 1990; Lane & Lubatkin, 1998). Zahra and George (2002) further developed the concept of an absorptive capacity and describe it as "a set of organizational routines and processes by which firms acquire, assimilate, transform, and ex-

ploit knowledge to produce a dynamic organizational capability" (p. 186). They differentiate the absorptive capacity of companies into the potential for acquisition and assimilation, on the one hand, and the capacity for realization in the form of transformation and exploitation, on the other. The routines and processes anchored in the organization are particularly important for the potential absorptive capacity. Implementation, on the other hand, describes routines for integrating new knowledge into existing processes within the company. The accumulation of knowledge and its processing does not take place in a linear process, but is dynamic insofar as the new unit of knowledge can enter from outside at any time, and the system is open to and dependent on constant feedback loops (Freeman, 2002; Lundvall, 2007; Nelson & Rosenberg, 1993). This applies both to the company as a system and to a national economy into which new information is carried from outside through other systems or information or knowledge units, which constantly rearrange the balance in the domestic system. In both systems, whether in the company or in the superordinate national system, the learning curve from accumulated experience plays a decisive role in influencing the ability to innovate. Thus, companies' R&D investments aim not only at the direct acquisition of new knowledge but also at the handling of internal existing; and new external, knowledge is improved concerning the identification, assimilation, and exploitation of knowledge (Lundvall, 2010). Here, incumbent firms differ from start-ups entering new markets in their ability to commercialize knowledge (Audretsch, 1995). Acs et al. (2005) describe the barrier that prevents some organizations from fully commercializing their knowledge as knowledge filters. Thus, innovations that are more radical are more likely to be achieved by start-ups, which, through their organizational form, are better able to adapt to dynamic markets (Audretsch, 1995; Seitz, Lehmann, & Haslanger, 2019). The ability to learn also becomes easier for smaller organizations, for example, because of flatter hierarchies and shorter information paths that provide advantages to process ideas. On the other hand, larger companies often have more experience in managing knowledge and a larger absolute knowledge stock (Mueller, 2006).

The "Systems" in NSIs: Social, Open, or Closed

The last section emphasized the importance of knowledge diffusion within a national system of innovation. Essentially tied to this notion is the recognition that systems are the pattern that enable and guide the direction and smooth flow of knowledge inherent in NSIs. For this reason, analyzing NSIs through the lens of systems theory proves useful.

Systems are characterized by the interaction of its linked multiple components within fixed boundaries. Therefore, systems theory incorporates other entities (e.g. technologies or individual agents) next to countries. The NSI framework is strongly linked to systems theory as systems describe a body of single connected parts that depend on each other. It is key to systems theory that the system as a whole entity provides more value than the sum of each individual part. It is impossible to change one part of the system without to change other parts within the system. Given external shocks, the systems' performance is determined by the capability of the system to adapt its components to changes of its environment. To this effect, systems usually follow a certain purpose, which also helps to keep the system alive and nurture the system with complementary resources. Organizations

are complex institutions and contain various and deep social systems. Each subsystem therefore fulfils a certain role for the total performance of the organization and cannot be easily taken away. It is key now for the further analysis to differ between models that apply a systemic view and other more conventional models that do not apply such a perspective. The latter focus their analysis on single parts of the system, such as individuals or single units, and separate these from the whole. Contrary to that, a view that applies the lens of systems thinking, build its analysis on the interrelatedness of the single units that together allow organizations to operate.

Following systems theory, a national system of innovation is a complex, closed or open, social cybernetic system, a patterned network of relationships constituting a coherent whole that exists among individuals, groups, and institutions, which can discriminate against outsiders by their shared attitudes of the "meaning" of the system and being a member of it. As a social system, a national system of innovation refers to a formal structure of roles and status that can be made up by a small, stable group, where individuals may belong to multiple social systems at once. Examples for a national system of innovation as a social system include innovators, inventors, incubators, universities, research parks, companies, cities, the political system and research labs, among others.

The general thinking of national systems of innovation in terms of systems theory could be divided into two broad concepts, viewing national systems of innovation as either a closed or open concept. This classification not only matters in systems theory but also for any theories that analyze who is in and who is out, and who decides and governs the boundaries and the entry and exit conditions.

Closed and open systems are linked with the terms "autopoiesis" (closed systems) and "allopiesis" (for open systems). The term "autopoiesis" is a combination of the Greek prefix *auto-*, meaning "self-," and the suffix *-poiesis*, meaning "creation, production" (Luhmann, 1986), thus literally translated as "self-creation" or "self-production." Autopoiesis refers to a system that is capable of reproducing and maintaining itself. The concept was first introduced in 1972 by Humberto Maturana and Francisco Varela, two Chilean biologists, to define the self-maintaining chemistry of living cells. Since the 1979 reprint of their book, first published in 1972 in Chile, the concept has been widely applied to the fields of cognition, systems theory, sociology, politics, business and management, and even economics.

An autopoietic system is to be contrasted with an allopoiesic system. An allopoiesic system (from the Greek prefix *allo-*, meaning "different" and the suffix *-poiesis*, meaning "creation, production"; hence, "different creation") produces or creates something different than the system itself. Assume a textbook economy, just described by the production function transforming raw materials and components as inputs to outputs. The outputs produced are something different from the production function, the system. An allopoeietic system of innovation, such as the NASA program "Man on the Moon" as announced by J. F. Kennedy in 1961, transforms inputs such as knowledge and physical capital, into in-

novative outputs like “Landing on the Moon.” It does not reproduce itself—say, as the NASA program.

By adding living and non-living components to the allopoietic production function and its environment, such as workers, universities, banks, research labs, customers, suppliers, competitors, tangible and intangible assets, fixed contracts and relationships, and so on, then as a total viable system it could be considered to be autopoietic system, that is, the national system of innovations could be capable of reproducing itself. As an autopoiesic system, a national system of innovation is a self-maintaining and self-organizing system, autonomous and operationally closed, in the sense that there are sufficient processes within it to maintain the whole. For simplicity, compare the complexity of the North Korean innovation system with the innovation systems of its environment. Without necessary resources from its environment, the North Korean system of innovation is, more or less, forced to reproduce itself as a self-maintaining and self-organizing system, autonomous and operationally closed. As a closed national system of innovation, the North Korean System is a self-contained entity that operates autonomously within fixed boundaries—the national boundaries of North Korea.[1] Such a national system of innovation is defined as “closed” if no materials enter or leave it (Bertalanffy, 1951, p. 23). Obviously, a closed national system of innovation is unlikely to benefit from international knowledge spillovers.

National systems of innovation as closed systems date at least back to the first concepts in management and organization, applying the idea of using a system perspective to understand organizations as systems, like Chester Barnard (1938), Henry Fayol (1949), or Frederic Taylor, (1911). Even a century after the seminal work of Frederic Taylor, the ideas of systems theory became popular in analyzing (economic) systems. The thinking about production units, assembling lines, management styles and organization of production and innovation has shaped the upcoming idea of thinking in terms of national systems of innovation long before the framework was made popular by Lundvall (1992) or Nelson (1993). Though Nelson, Lundvall, and others majorly contributed to formalize the concept of NSIs, their framework uses elements that had been already described by a number of authors long before.

In the realm of internalization and globalization, technology transfer and cross-border innovation projects around the globe have become the narrative in the late 20th century. This has rendered the view of national systems of innovation in a broader context. Today, in analogy to Bertalanffy (1951, p. 23), they are defined as open because there is import or export and therefore a change of the components. Bertalanffy (1951) emphasized the idea that real systems are open to their environment and interact with the environment, which results in continual changes and evolution. Katz and Kahn (1966) and Thompson (1967) introduced the idea of open systems into the management literature, describing the systems perspective as basically concerned with problems of relationships, structure, and interdependence. Since then, thinking in open systems has become the dominant perspective in management and organization science. Each unit or organization is part of the external environment of other organizations, and individuals are concerned to exert economic, political, and social influence on the focal organization. An open national system of

innovation thus operates and interacts continuously with the environment, and the boundaries are rather flexible and not exactly defined. National systems of innovation in the European Union, for example, operate with interlinked research and innovation programs, like the European aerospace program and the European research funds, among others. The external environment provides critical resources that enable the organization to persist and evolve over time, but also makes the organization dependent on others to obtain these resources.[2]

The Need for Active Governance

The final part of "DIMENSIONS OF NSIS" aims at highlighting the role of governance and public policy to manage the incentive schemes of actors and their ability to share and deploy resources. A governance perspective for NSIs is focused on learning who controls the national system of innovation and how the distribution of power and influence arise. The interest in these two questions connects the main characteristics of national systems of innovation.

Innovation systems are seen as loosely coupled with their environment, something which makes external relationships outside the system important, but at the same time interdependent. These indeterminate relationships allow potential variations in how national systems of innovation are able to manage constraints in their environment. These potential variations are a key trigger for the analysis of national systems of innovation, as they point to the value of understanding how the distribution of power within and around the innovation system influences and shapes its structure and behavior. The seminal work of Pfeffer and Salanzcik (1978) uses a resource-dependence approach to analyze how external constraints affect organizations and how organizations control these constraints. Here, their approach could serve as a starting point for analyzing the patterns of national systems of innovation from a systems perspective and, in particular, how conflicts of interest and power influence structures and patterns of behavior of national systems of innovation that may arise. They introduce co-optation as a mechanism to cope with the tensions and dilemmas caused by structural arrangements and environmental constraints. Co-optation in the context of national systems of innovation means inviting outside and external critical sources of constraint, like finance, knowledge, technology, or human capital, into the internal decision-making or advisory structure of the national system of innovation, with the aim of averting threats to its stability or existence and thus trading some of the national systems of innovation autonomy for support (see Selznick, 1949, in particular p. 13). Borrowing from systems theory, national systems of innovation can be viewed as a set of social relations and networks than cause interdependencies that in turn are used for exerting influence on one another within the system.

Thus, one reason that explains performance differences among different NSIs stems from the allocation of power relations within the system. Known for his work on social-exchange theory, Emerson (1962) argued that power is foremost a function of the interdependencies among actors and not of the sole specific actor; therefore, the governance of an NSI is essential to distribute information and other resources in a way so that all NSI

components can provide inputs for the system complementarily. The power relations inherent to the NSI shape the exchange relationships of all actors within the NSI, as the evaluation of resources of others and the relative value of alternative exchange possibilities explain the availability of shared resources. Agents that control the most valuable resources, therefore, are most likely to have a high, or even the highest, level of power within the NSI. For this reason, the governance of the NSI should focus on relationships that control highly valuable resources and work toward a balance of power.

As an open system, a national system of innovation is contrasted with the concept of an isolated system, which exchanges neither information nor resources with its environment, that is, other nations. In a closed system, all the social interactions and flows of information end at the national boundary, a countries borderline. This is best described in traditional economic theory as the “closed economy models,” like North Korea, for example. As a closed system, a national system of innovation is characterized as a constant volume system or a flow system, which implies certain consequences. A closed system only grants access to a restricted pool of resources.

Open systems follow the rational that its resource base cannot be consumed completely. The supply is provided by environment, which is assumed to be unlimited. Open systems therefore exchange all kinds of resources, such as capital (individuals as human capital, e.g.) or information. Closed systems instead, actually follow clear cause-and-effect relationship over the different stages of the systems, once it comes into existence, such as a car’s engine that only works once its power button (at least in modern cars) is pressed.

The procedure of open and closed system could not be any more contrary. An NSI clearly is quite a complex system and consists of various components. The different parts exchange all kinds of resources with one another and react to the information provided by others within the system. The modeling of an NSI is not easy to describe precisely, because of the various complex relationships of these components and the embeddedness of the NSI its in context. It is key to understand that complex systems exhibit properties that emerge due the various complex relationships, such as missing linearity, spontaneous order or feedback loops.

As a cybernetic system, national systems of innovation are characterized by the communication and control of regulatory feedback, for the environment and the interactions in the complex of living (i.e., individuals, decision-making units) and non-living (physical resources, infrastructures, or buildings, among others) components and the interrelated mix of those. As a cybernetic system, it scrutinizes how anything digital, mechanical, or social regulates its behavior. Additionally, its focus lies in how it responds to changes and new information within the system and how it faces the handling of primary goals and challenges.

Having learnt from the line of reasoning above that an active governance is needed to allocate power, public policy is given the mandate to implement this. As noted further above, the knowledge and skill base of countries must stay parallel to the knowledge intensity of products and services, whereby this learning curve is driven by high-tech inno-

vations and the demands of specialized knowledge in today's information society. In this context, public policy has a special role to play in coordinating the main actors—companies and university researchers—in order to keep the societal learning curve up to date with advancing technology accumulation (Etzkowitz & Leydesdorff, 2000). This learning curve is shaped equally by public and private investment—and systems at the national level differ in terms of their weighting of private and public nature (Filipetti & Archibugi, 2011, Lehmann et al., 2019; Lundvall, 1999).

Preliminary attempts to analyze and elaborate a systematic interpretation of the set of interdependent and structured interactions shaping an economy's learning curve and the coordination and institutional mechanisms underlying the generation, exploitation, and accumulation of technological knowledge are grounded in Schumpeterian growth regimes (Antonelli, 2019, p. 4). The notion of growth regimes enables understanding of the endogeneity of growth and change driven by the accumulation of knowledge, innovations, and human capital (Romer, 1990), and shows how to organize a system (e.g., country) to shape the governance of the generation, exploitation, and accumulation of technological knowledge and its macroeconomic dynamics (Antonelli, 2015). This constitutes the emergence of the NSI as a framework to ensure that a nation's learning curve keeps up to date with advancing technology accumulation by focusing on both the push side of the creation of innovations and the pull side of exploitation and absorption of innovations to shape economic performance and the competitiveness of nations.

Despite the plenitude of possible complementarities among patterns that might seem coherent on the first look, to "mix and match" (Roberts, 2004, p. 39) these patterns and the given context and choice variables (Audretsch, Lehmann, & Schenkenhofer, 2020) will not work as an efficient solution. Therefore, innovation needs to be governed strategically on a national level to circumvent a rather loose "mix and match" strategy. And this is right where NSI approach steps in to organize innovation and learning routines to govern the strategic success of knowledge creation and development of future technologies. The NSI approach places institutions in the foreground and their ability to shape the context in which firms and research institutes strive for innovation (Acs, Audretsch, Lehmann, & Licht, 2016; Audretsch et al., 2015; Filipetti & Archibugi, 2011). Of course, governing NSI implies to focus on such institutions most, that have the greatest impact on stimulating innovation, such as education, scientific research, industry networking among others. For this reason, governing NSI implies to pay special attention to actors such as research institutes and technologically driven companies (Audretsch et al., 2015) and furthermore to invest in the complementarity of the latter. The interaction of these core actors is one of the key tasks when governing an NSI. Successfully pushing innovation is strongly tied to discovering matching patterns and dissolving mismatches. Efficiency gains by certain countries emerge majorly because of mismatches within the institutional patterns of NSI. Only complementary arrangements will contribute to the success of an NSI, which is strongly linked to the development of knowledge stock that both is high in its absolute quantity, but even more important, fits into to the overall system with regard to the type of knowledge that is accumulated. Differences of national economies with regard to the various innovation performance measures emerge from these bottlenecks (Link, 2015A,

2015B). Some countries exhibit a different culture for entrepreneurship than others do. While some countries rank higher with regard to second chancing and fear of failure, other countries punish failed entrepreneurs, which inevitably involves backlashes for the incentive to bear risk and become entrepreneurs, for the whole society (Audretsch & Lehmann, 2016).

To further exemplify the importance of coherence among the various components of an NSI, the Global Entrepreneurship and Development Index, GEDI, explains how certain pillars within the coherent system affect the performance of other pillars (Acs et al., 2014). Whenever one pillar exhibits a low performance, other pillars will experience a penalty. This idea of bottleneck penalty for the overall system allows to make well informed decisions to infer complementary and precise policy measures. Acs, Audretsch, Lehmann, & Licht (2017A) infer a number of important insight from this for policy and management decisions. The bottleneck algorithm helps to understand why the innovation policies of countries is changing steadily and therefore repeatedly implementing shifts of their institutional environment. One example is the shift of centralized to decentralized policies and vice versa in their nature to form policy measures. Second, the framework of Acs et al. (2014) points out that several viable patterns of institutional arrangements exist than can establish consistent patterns. Given the national landscape of firm types and its prevalent model of entrepreneurship, policies targeting high-tech start-ups may prove to be more successful in countries that rather emulate a scale economy (Audretsch et al., 2020) and benefit from a higher number of large and public companies. Such policies could prove to be less efficient in countries that rather emulate a niche economy of where many SME type firms reside.

Conclusion and Recommendations for Further Reading

Drawing a conclusion, the field of NSIs has developed along the insight that different institutional settings within economies are the main drivers behind what guides economic growth. The innovativeness of countries is responsible for how countries are capable of responding to the dynamics inherent within economic processes. Therefore, the determinants of a country’s innovation capability are of high importance to understand how and why nations differ regarding their NSI type and manifestation. The accumulation of knowledge, both in type and quantity, is key to fostering a country’s innovation output (Johnson, Edquist, & Lundvall, 2004; Nelson, 1992). Thus, the sources of knowledge, by both private and public investments in research and R&D, precede the commercialization through firms. Public policy serves as a moderator within NSIs to guide technological learning activities and the networks of universities, firms, and governance, to allow smooth flows of both knowledge and information. This is attained by public policy makers taking a bird’s eye view to understand how the underlying system works in order to improve it in a way such that all actors involved benefit, given a mutual dependence among the actors. Thus, public policy makers have the capability of detecting potential opportu-

nities for efficiency gains and of working on the interplay of relevant actors to allocate and distribute resources adequately.

The national systems of innovation approach is a fundamental method that enables one to understand the mechanisms and channels of knowledge interactions on the national level. A seminal contribution on fundamental thinking about innovations is Antonelli's (2019) "Schumpeterian Growth Regimes." His chapter is part of an edited volume by Audretsch, Lehmann, and Link (2019) that provides a research agenda highlighting new insights and approaches to guide future thinking in the area of innovation and public innovation policy. Within his 2010 book *National Systems of Innovation: Toward a Theory of Innovation and Interactive Learning*, Bengt-Åke Lundvall focuses on the dynamics of the national and global economy. He essentially grounds his analysis in the view that the competitiveness of nations is essentially influenced by a nation's capability to innovate through interactive learning processes.

The national systems of innovation approach is an interdisciplinary field linking economics, business, and politics. Many of the "hot issues" of national systems of innovation are summarized in surveys and essays, which are essential reading. An indispensable "must read" is the article *Advanced Introduction to National Innovation Systems* by Chaminade et al. (2018), who provide an impressive picture of the past and present research on NSIs. Chaminade et al. introduce and discuss different concepts, including the narrow and broader concepts used in theory and practice, thus providing a comprehensive mix of old and new ideas of different perspectives on NSIs.

Another highly recommended study is by Jorge Niosi, published in *Research Policy* in 2002. His work targets the efficiency of NSIs and studies whether NSIs are "x-inefficient." Methods to measure the efficiency and effectiveness of NSIs are discussed, as well as some of the main factors that eventually cause the inefficiency of NSIs. Finally, Filippetti and Archibugi (2011) research the innovation processes in times of economic crisis and to what extent different NSI characteristics affect the resilience of firm-level investment in innovation. Important factors that determine the resilience of countries consist of the competences and quality of the human resources, the specialization in the high-technology sector, and the development of a country's financial system.

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Notes:

(1.) Even the boundaries of North Korea are not as fixed as assumed for a totally closed system. Via the Internet and personnel contacts, knowledge generated outside the country could be exploited as critical resources.

(2.) The Swiss system of innovation strongly depends on resources outside the country, like human capital embodied in researchers and graduates from abroad. The system seems to be also dependent on European research grants and international research projects. The same holds for the United Kingdom, where the national system of innovation is said to be critically affected by BREXIT.

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