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Exploring the impact of open innovation on national systems of innovation — A theoretical analysis

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ABSTRACT

This paper investigates the impact of open innovation on national systems of innovation. The open innovation concept has become widely established among scholars and practitioners. However, an overview of its impact on national innovation systems is still lacking. Given that the innovating firm is at the core of national innovation systems, a better understanding of shifting innovation strategies at the firm level is of fundamental importance to the actions of policy-makers within the national innovation systems framework. Based on the main analytical approaches of national innovation systems and the current state of open innovation research, we argue that open innovation practices have at least three critical effects on national systems of innovation: (a) they reinforce its importance; (b) they improve its effectiveness; and (c) they diversify its networks.

1. Introduction

Nowadays, no single company, not even the manufacturing giants, can monopolise the knowledge landscape as it used to be the case [1,2]. The knowledge landscape is fairly heterogeneous, with a wide variety of players (firms of various sizes, universities, research institutes), each focusing on different pieces of the puzzle. As a result, the means of organising innovation have moved beyond the boundaries of the firm towards the concept of 'open innovation', a term coined by Chesbrough [3]. Open innovation (OI) can be defined as 'the use of purposive inflows and outflows of knowledge to accelerate internal innovation and to expand the markets for external use of innovation, respectively' [4, p. 1]. According to Chesbrough [3,4] OI requires that a firm creates value and captures value using technologies developed by others or enabling others to use its technology. When a company creates value using technology from the outside it can scout for several sources of technology or ideas. First, companies can license-in technologies. Second, they can establish different types of alliances to co-develop innovations with partners. Third, they can use brokers (e.g. Innocentive) to reach a large number of researchers or technicians worldwide. Fourth, companies can spin-in or acquire high-tech companies to gain access to particular types of technology. Finally, they can source external knowledge from communities of practitioners, customers or specialists usually referred to as "open source". These are all enablers of open innovation that co-exist and jointly stimulate innovative performance.

The ability of firms to apply OI practices rests on a large number of external factors. In particular, open innovation practices are positively affected by: A continuous supply of outside knowledge; highly-educated personnel; financial resources; effective legal systems; institutions protecting IP rights. Most of these factors are closely related to a country's national system of innovation (NSI) [5,6]. A general definition of NSI is the set of institutions, actors, and relationships that individually and jointly influence a nation's cumulative innovative performance. Chesbrough [3] models the relationship between NSI and OI when he illustrates how

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structural changes in the US' NSI have created a widely-distributed knowledge landscape since World War II as a result of: Greater availability of highly-educated workers; venture capital; state-of-the-art knowledge. Furthermore, the author concludes that the resulting changes in NSI stimulated and accelerated the emergence of OI in the US.

Yet apart from Chesbrough's 2003 pioneering work, there are few studies exploring the important relationship between OI and NSI (a notable exception is De Jong, Kalvet, and Vanhaverbeke [7]). This is because the burgeoning literature on OI has largely focused on firm-centred analyses, which generally disregard the relations between firms and their external context. Most recent publications in this field focus on enhancing the OI framework and establishing its general validity [8,9]. Similarly, the large body of literature on NSI takes the structures, functions, and effectiveness of NSI as the main focus. This approach largely ignores new developments taking place at the firm level, where OI practices are increasingly used to organise companies' innovations [10]. Therefore, few recent papers on NSI have analysed the paramount relationship between NSI and OI — despite the fact that it is precisely this relationship that may be crucial for policy-making.

Close scrutiny of the current literature on NSI reveals that there are three different approaches to examining NSI, which have been developed separately. We will briefly describe these structural, functional, and effectiveness approaches to gain a balanced view of NSI. First, the structural approach is the most traditional and widely-used tool employed in NSI research. It focuses heavily on identifying structural elements that influence innovative performance within a system [11]. Second, the functional approach is a new development for NSI research that concentrates on how various functions are served by the system. That is, what are the most important activities and processes taking place within an NSI? These functions constitute an intermediate level construct between the structural elements of an NSI and its performance [12]. Third, there are many publications on NSI that focus on the effectiveness of innovation systems [13] where research covers performance assessment, system failures, and the efficient evaluation of input-output.

This balanced view on NSI provides us with a baseline for exploring the impact of OI on NSI. In this study, we explore how a country's NSI structures, functions, and effectiveness are influenced when firms change their innovation strategies towards an OI paradigm. The structure and functioning of a country's existing NSI also has an impact on the way companies deal with OI practices but this side of the coin has already been dealt with in another study [14]. Here, we focus on how changing innovation practices at the firm level impact the NSI.

This study contributes to the literature and policy-making in the following ways. First, it encourages OI scholars to conduct their research within a broader economic growth perspective as this paper reveals that OI practices are closely connected to a country's specific innovative context. Second, it provides policy-makers with a better understanding of why an NSI needs to be adjusted when companies are adapting their approach to innovation. Given the new OI practices of companies, it is reasonable to assume that an NSI needs to evolve in the direction of a so-called national system of open innovation. Offering policy-makers an enhanced understanding of why current trends in corporate OI need to be taken into account when drawing up public policies may be very useful.

This paper is structured as follows. The first section introduces the main NSI analytical models. These approaches will be used to get a balanced view of an NSI, which, in turn, provides us with a good starting point for examining how corporate OI practices influence an NSI. The second section explores the impact of firm-level OI practices on an NSI. The third and final section sets out our conclusions and their implications for policy-makers.

2. Three approaches to NSI

Since the 1980s the NSI concept has been developed and built on by a host of scholars [11,15]. A commonly used definition of NSI is: "The network of institutions in the public and private sectors whose activities and interactions imitate, import, modify, and diffuse new technologies" [11]. Lundvall [15] draws a clear distinction between a narrow and a broad definition of NSI. Nelson et al. [11] perceive NSI as a set of institutions whose interactions determine the innovative performance of a country. Although there is no single definition of NSI, most scholars share the core view that a country's NSI pursues some given goals, is spun by institutions, organisations, and interrelationships and all these elements form the woof and the weft of nation-specific contexts. We find that the current NSI literature is scattered and that at least three approaches have been separately developed over the last two decades. We label them the structural, functional, and effectiveness approaches. To clarify several NSI dimensions we briefly describe them below. Each of these dimensions will, in turn, be used as starting points for our analysis of the impact of OI practices on a country's NSI.

The *structural approach* identifies and describes structural elements in different types of innovation systems. This approach, which uses these structural elements to explain differences in innovative performances of various systems [11,15], has been the most common one since the NSI was first articulated by Freeman in 1987. Structural analysis focuses on the national level of innovative activities and the structures spawned by companies, universities, research institutes, government agencies, public policies, institutions, and, in particular, the various relationships among them. Coherent corporate behaviour in the innovation field is shaped by national culture, laws, norms, and conventions [16]. The structural view of NSI primarily aims to identify the main determinants influencing the production, use, and dissemination of new technologies in a given country or region.

The *functional approach* to NSI focuses on the activities and processes that the main actors within an NSI carry out for the purpose of knowledge generation, dissemination, and application [12,17–19]. A function can be defined as the contribution of one or a set of activities to an NSI goal [19]. Such functions might be: fostering technology markets; setting up linkages; stimulating education and training; setting up IPR protection; mobilising resources; providing knowledge [20]. A combination of several NSI functions is generally referred to as a functional portfolio, which can be used to study NSI dynamics by mapping various portfolios over time [12].

The *effectiveness approach* takes into account the complex nature of NSI where most actors and elements of NSI are 'socially embedded' and the mechanisms used to co-ordinate them are non-market mechanisms: Institutional, networking, and policy mechanisms are employed to co-ordinate actors in an NSI [21]. The effectiveness approach focuses on: assessing a system's performance; input-output efficiency; diagnosing systemic failures hindering NSI development and operation; setting the benchmark and developing linked indicators [13].

These approaches are developed separately and they emphasise different NSI characteristics. In order to discuss the impact of OI practices on NSI, a single approach cannot be relied upon as this might bias the results. Therefore, we prefer to have a balanced view on NSI based on the aforementioned approaches. This should give us a more detailed, complete picture of what an NSI is, which, in turn, may facilitate our study of OI impact on NSI. As Lundvall [16] states, NSI are purposively supposed to achieve a certain goal in an attempt to capture the process of knowledge generation, dissemination, and use. Its ultimate goals are economic growth, job creation, and acquisition of international skills. Each innovation system performs differently in achieving its supposed aims. This principle is the underpinning for the effectiveness approach. Consequently, this approach provides a starting point for analysing the impact of OI on NSI: corporate OI and its effect on NSI effectiveness therefore lie at the core of our analysis. Subsequently, we examine functions, processes or activities, following the functional approach. As a result, we can say to what extent functions in innovation systems are 'achieved' through open innovation. However, the major weakness of the functional approach is a lack of clear and practical implications for policy-making. In contrast, the structural approach [12] pays sufficient attention to identifying the most important factors in national systems of innovation. Thus it can help us determine OI's main policy implications. In the following section, we consider the impact of OI on NSI in detail, using the approaches just described.

3. The impact of open innovation on NSI

In contrast to the internally integrated model of innovation explained by Chandler et al. [22], the OI model presents a way of explaining how firms have come to organise their innovations so as to make full use of both internal and external innovations [9]. Given that innovative firms lie at the heart of NSI and are vital to public policy design [16], we assume that this new development cannot be overlooked when studying NSI.[1] Consequently, investigating the impact of OI on NSI is likely to benefit both streams of OI and NSI studies. In the first two sections we describe the impact of open OI practices on the functions and effectiveness of NSI. The last section addresses the impact of OI on the NSI structural perspective.

3.1. Open innovation reinforces the importance of NSI

OI practices depend heavily on the internal capability of firms to leverage outbound and inbound knowledge and on the availability of sufficient external knowledge and other important resources. The supply of external knowledge is largely determined by a well-equipped functional NSI. This strong interdependence makes NSI more important than ever before. Hereafter, we focus on the formation of technology markets, linkages, IPR protection, knowledge development (basic research), and education and training.

3.2. Undeveloped technology markets need to be cultivated in NSI

OI broadens the range of external technology sourcing modes by embracing alliances and acquisitions, technology markets, and corporate venture capital (CVC) [3,23]. In technology markets, firms purchase, sell, and use technologies developed by other firms to complement their internal technology base [24]. Technology markets therefore play a key role in OI practices. Chesbrough [4] claims that technology markets (especially innovation intermediary markets) are a critical enabler for OI. Rigby et al. [25] use the term *open-market innovation* to map the burgeoning use of technology markets by firms for innovation purposes.

However, in contrast to most intangible markets, technology markets generally result in high transaction costs because they are imperfect [1,26]. Therefore, a reduction in imperfections would lead to a greater use of technology markets. Teece [27] emphasises the importance of improving the IPR regime and the legal system. Gambardella et al. [28] argue that the use of technology markets could be boosted if policies hindering the emergence of supporting institutions could be removed. Even so, the current literature on NSI and public policy largely overlooks this increasingly important function [29,30]. Hence there is an urgent need to foster technology markets in NSI.

[1] Open innovation is a new term coined by Chesbrough in 2003 but collaborative innovation agreements between companies such as technology alliances, joint ventures, technology licensing etc. have been analysed since the 1970s and 1980s. We believe, however, that open innovation represents a quantum leap with respect to the previous literature on collaborative innovation strategies. First, open innovation emphasises that innovating companies have to make full use of both internal and external innovations. External sources of innovations are as important as internal ones and this balance was not present in previous literature. Second, open innovation offers a unified framework in which a firm's innovation strategy, the choice between external technology sourcing modes, the creation of absorptive capacity, and business model thinking are tightly linked to each other. Finally, the buzz on open innovation has triggered many firms to redirect their innovation strategy in new ways. We argue that open innovation and its influence on NSI deserve attention from researchers and policy-makers for two reasons: First, open innovation cannot be considered as a simple extension of the previous literature on collaborative research. Second, the balance between internal and external sourcing of ideas indicates that the way innovating firms reach out to other organisations in the NSI is of much greater importance than hitherto.

3.3. Linkages within NSI need to be strengthened to facilitate the increasingly wide use of innovative networks

In the OI realm, using inter-organisational collaborative agreements and networks to harness external knowledge flows among organisations is a key dimension. In itself, OI can almost be seen as a specific approach covering the links that innovating firms forge with other organisations [31]. With a paradigmatic shift from closed innovation to open innovation has come a shift in the locus of innovation from large companies to networks [32]. Prior research has demonstrated the major advantages of innovation networks for coordinating both tacit and explicit knowledge flows, and further research shows a positive effect of firms' presence in such networks on their innovative performance [33–36]. However, existing NSI literature does not sufficiently challenge the 'closed innovation paradigm' for most networked innovations, which still centre on internal R&D [4]. Open innovation scholars argue that firms use networks to source external knowledge for internal use and to market unused internal technologies [37]. Inter-organisational networks are an increasingly important channel for implementing OI. However, this cannot be expected to take place in an NSI in which closed innovation thinking prevails [38].

Innovation networks are likely to be more widely used in the OI era than ever before and this in turn means a need for stronger NSI linkages. Actually, this argument is consistent with the NSI core concept whereby multifarious efforts foster different kinds of collaboration and networking activity [39,40]. Specifically, a stronger linkage between public and private sectors is imperative in the era of OI [37]. Thus, the increasing development of OI practices is strongly reliant on forging ties among the key innovation players [41].

3.4. Efficient flows of knowledge heavily depend on stronger IPR protection

OI practices involve abundant inbound and outbound flows of knowledge. Inside-out and outside-in flows entail patent licencing, technology-based acquisition, joint-ventures, non-equity R&D investments, and increasingly, direct technology buying or selling. Traditionally, consortia agreements have allowed information flows and technology collaboration only within a consortium, whose membership is limited to just a few companies [42]. Obviously, OI is not restricted to these tight forms of technological collaboration and embraces the global innovation community as its knowledge base [43].

However, the efficiency of knowledge flows is directly linked to a country's regime for knowledge appropriation. Earlier NSI studies have shown that a well-defined system of intellectual property protection can ease knowledge flows [44]. In view of this demand for knowledge flows, NSI scholars have listed IPR protection as one of the key functions within a portfolio and have widely discussed it [6,45–47]. Therefore, enabling OI practices means improving and strengthening the IPR protection system and related legal regime [48] within the NSI framework. This is one of the most important requisites for OI practices.

The 'seed corn' of OI relies on major public support for basic research

OI shows that companies are shortening their time horizons for R&D expenses and are shifting the focus of their internal efforts from basic research to more immediate application-oriented innovations [3]. This implies that industry can no longer be expected to underwrite the bulk of basic research costs. The spate of innovations from these laboratories over the past forty years is likely to dry up in the near future, given this shift in orientation made by major labs. This trend is also reflected in the fact that most of the world-famous corporate R&D laboratories of the twentieth century have been downsized, broken up, or redirected to new goals [49].

Basic research is critical as 'seed corn' for new waves of innovations and greatly enriches the knowledge landscape. Public support for basic research has long been a tradition in most countries [50]. However, in recent years, some counties, such as the U.S., have slashed public funding [51]. This seems inconsistent with the development of the OI principle. A basic insight of OI is that there is a new division of innovative efforts between industry, government, and academia with less basic research being conducted inside large corporate labs [49]. Only two decades ago, large industrial companies had vast corporate R&D centres, which had greater scientific and technological capabilities than most universities. The majority of these central labs were dismantled – especially during the 1990s – as big companies were pressured by shareholders to focus on short-term profits. Long-term research was increasingly seen as too expensive. In consequence, as companies focused more and more on applied sciences and the development and commercialisation of technologies, universities became the sole institutions targeting basic research. In this way, the position of basic research became weaker in the innovation ecosystem of different countries. Therefore, governments and universities face the challenge of stimulating efforts in basic research by providing public funds for most of the 'seed corn' research. This can in turn spur the major innovations of the next two decades [8,52]. Instead of weakening public support for basic research, this NSI role may need to be beefed up.

3.5. The supply of high-quality labour is strongly linked to education and training

One of the crucial elements holding the open innovation system together is its human and social capital. As Chesbrough [3] states, a high-quality labour force is one of the major prerequisites of OI as it allows knowledge to spill over to other organisations and boosts firms' ability to absorb innovations [53]. This also applies to the recruitment of graduates by firms, which is probably one of the main mechanisms for making money from fundamental research [54]. Hence the stress often laid on the roles played by education and training in stimulating OI [55]. Better education and training will strengthen many of the behavioural aspects of OI, including networking and collaboration skills, corporate entrepreneurship, the ability to license technologies, and carrying out R&D. Developing and maintaining a skilled labour force requires governments to deliver and implement high-quality education at all levels. In addition, policy-makers need to address post-graduate training and 'lifelong learning' for a society's human capital as well [56]. In general, education and training are at the heart of a public policy for fostering OI. Therefore we cannot ignore the importance of NSI in pursuing the open innovation model.

This section explored how open innovation influences the functional perspective of NSI. We argued that rising use of the OI approach boosts NSI importance in at least five areas: fostering technology markets; establishing stronger linkages within NSI; IPR protection; funding basic research; ensuring the supply of high quality personnel. All of these are closely linked to the performance of NSI functions.

3.6. Open innovation improves the effectiveness of NSI

The effectiveness of NSI is the extent to which the system attains its general goal or carries out its mission [13]. In reviewing the literature on the effectiveness of NSI, we find that scholars typically concentrate on market distortions [57,58] and system failures [59–61]. Empirical studies are directly linked to static (input/output) indicators such as R&D expenditures, patents, and bibliometric data [62]. Generally speaking, such studies have detected most of the factors and mechanisms influencing the effectiveness of systems. However, as some authors claim, there are still a number of factors and mechanisms that have been poorly explored. For instance, Oreland et al. [63] states that knowledge transfer mechanisms have a critical impact on the effectiveness of systems. Porter [64] draws attention to the importance of institutional factors such as the effectiveness of the R&D system and networks between firms.

In our study, we suggest mechanisms through the lens of OI that may enhance our understanding of the effectiveness of NSI. In particular, we focus on: the social wellsprings of innovations; strong specialisation in innovative labour; the efficiency of resource allocation; accelerating knowledge flows at lower costs.

3.7. Eliciting social resources for innovation

In modern society, innovation is vital for countries in building up their competitive advantage and providing sufficient social welfare to their citizens [11,65]. Successful innovation requires sufficient resources to be earmarked to on-going discoveries, knowledge generation and dissemination, and technical development [29]. Earlier NSI studies have focused almost solely on mobilising public and private resources for technological innovations and have suggested two complementary investment models [66]. The first is the ‘private investment’ model, which assumes that innovation can be funded by private sources and that private returns can be appropriated from such investments [67]. The second is the ‘collective model’, which fosters innovation through direct public investments in public knowledge goods [68]. This model also progressively employs policy instruments to promote private investments in R&D [69]. Examples of such policy instruments are competition policies, tax policies, and subsidies. Therefore, prior to the OI era, innovation came about either through private R&D spending in firms or through government investments in the public sphere [70]. A vast range of social resources, such as retired skilled workers, and the valuable knowledge of former staff, have been generally excluded from the task of advancing the frontiers of innovation. OI scholars state that in the OI era, companies should tap into this large external pool of know-how to gain new ideas while at the same time move unused ideas outside the company [3]. This leads to a large, valuable stock of knowledge for others and additional revenues for the firm itself.

Researchers in OI claim that valuable knowledge can be generated through resources other than those provided by firms and governments [36]. Valuable knowledge can be produced through a broad range of instruments, including blogs and internet-based communities [38]. A typical example of using social resources to innovate is the popular phenomenon of open source software [71] and the current Threadless Community [72], revealing ‘a third model’ that draws upon extensive social resources to create valuable public knowledge. This model is termed the ‘private-collective’ model by von Hippel et al. [71] and is an unusual collaborative effort where skills in firms, sectors, and nations offer a vast pool of public knowledge. OI thereby generates a unique way of eliciting and co-ordinating the efforts of scattered individuals in an internet-oriented knowledge base. This provides great potential for a country to increase the level of knowledge creation in society and further improve NSI effectiveness.

3.8. Benefiting from strong specialisation in innovative labour

Economists have shown that the growth of a more complex division of labour is closely bound to the growth of total production and trade, which strengthens a country's competitiveness [73]. When closed innovation prevailed, the economy of specialisation was largely confined within firms [74]. A study by Arora et al. [75] shows that a decline of research productivity inevitably occurs when research-oriented firms integrate manufacturing and marketing units. They further claim that small innovating firms may be inefficient at building downstream assets, making the commercial exploitation of new technology riskier and less efficient. Large companies are generally better at exploitation than exploration and may be better adapted to making incremental improvements to existing technologies than pioneering new discoveries [76]. There is a natural labour division in knowledge generation and commercialisation between firms of different sizes. Consequently, there is a major opportunity to benefit from this strong division of labour through an open innovation model.

OI theory purports that innovators do not necessarily implement all innovation stages, thus profiting from the division of labour in this field. In particular, innovating firms can choose to sell technologies instead of investing in the downstream assets required to commercialise technologies or they can choose to buy new technologies instead of creating them in expensive in-house R&D labs [49]. Through this innovative labour specialisation, companies may be able to focus their strengths on some parts of innovation value networks. This, in turn, boosts both the competitive capacity of the value network and the effectiveness of a country's NSI [77].

3.9. Improving the efficiency of resource allocation

Innovation is a risky undertaking that requires the allocation of financial and intellectual resources under specific conditions. At the company level, the innovative resource allocation process has been widely discussed in the context of the Bower–Burgelman model [78,79], which is aligned with the closed innovation paradigm where resource allocation is confined within firms [80]. This generates two types of efficiency losses, one for the company and the other for society at large.

In general firms are aiming for sustainable success while allocating scarce resources to costly R&D activities. The likely result is extended patent portfolios. According to Chesbrough's [49] survey, around 25% of patents are never used in any of the patent holders' businesses and most innovations and IP sit on the shelf unused. This is a major waste of scarce corporate resources. From society's point of view, the loss is even greater. If companies never use some of the technologies they are creating or license-out these technologies to other companies for the purpose of commercialisation, then the products covered by the temporary monopoly are never brought to market. Therefore, society never gets to experience the use of these new inventions, and policy-makers also empower companies to prevent anyone else from using the technology until the patents expire.

As innovation orientation changes from internal R&D to the growing use of external innovation, the Bower–Burgelman model gradually becomes obsolete and sub-optimised. As Maula [81] suggests for the OI process, allocation of resources will shift from the focal corporation to the developer community and external partners, such as joint ventures and university research. In this way, resource allocation efficiency will be gained at two levels. At the firm level, innovating firms using this new model can manage the innovation community successfully over different time horizons [70] by leveraging internal and external innovators. In addition, active R&D resource sharing generally widens firms' R&D reach and greatly reduces unnecessary duplication. From society's point of view, OI provides greater scope for jointly configuring the best ideas and business models. In other words, OI strives to come up with the best ideas and the most suitable business models for commercialisation [49,82]. As a result, OI improves resource allocation at the macro level and yields benefits for all concerned [57].

3.10. Accelerating knowledge flows at low transaction costs

The NSI approach stresses the power of knowledge transfer and dissemination [83]. Public policy thus often seeks to boost knowledge flows in order to synthesise and strengthen the general purpose of NSI. During the era of closed innovation, most innovating firms were reluctant to transfer knowledge, particularly outside the bounds of the company. For instance, patents (the most tradable knowledge assets) were commonly treated like The Crown Jewels rather than media for knowledge exchange. The arrow information paradox, the NIH syndrome, untapped technology markets, and hold-up problems used to prevent low-cost knowledge transfer [84–86].

Conversely, in an OI era, knowledge transfer is primarily driven by firms' desire to advance current business models, nurture new businesses, or sell unused technologies to create additional revenues [49]. These intrinsic reasons are fuelled by the growing number of innovation intermediaries, which, in turn speed up the circulation of global knowledge. Innovation intermediaries create a link between innovating firms and the global innovation community and help firms enhance their OI capabilities by exploiting the most valuable and context-specific tacit knowledge [43]. At the same time, wider use of different types of networks boosts knowledge transfer, given that intermediaries' *raison d'être* is to convey firms' inbound and outbound knowledge [87,88]. Increasingly efficient technology markets mean that companies no longer need to acquire and sell other companies to access the underlying ideas and technologies. Consequently, much potentially valuable trade in innovation and its associated IP becomes less expensive [44,49,89]. Companies can extract value from technology without having to spend a lot of time and scarce resources on developing manufacturing, distributing, and marketing capabilities. As scholars are quick to claim, OI alleviates the AIP, NIH, and hold-up problems [49] and so fosters knowledge transfer at low transaction costs, which, in turn, enhances NSI effectiveness.

3.11. Open innovation diversifies the networks used in NSI

Structural elements in NSI include institutions, other players and their myriad relationships [11]. The most important players are firms, universities, venture capital organisations, and public agencies charged with innovation policy [29]. Institutions embrace legislation, customs, and conventions. Culture and relationships refer to the various kinds of market and non-market relationships [15]. In the OI age, we have to consider the emergence of new elements in NSI, such as innovation intermediaries, technology markets in physical and electronic forms, specialist technology suppliers and buyers, and so on [1,8,43,49]. At the same time, the widespread use of external innovation tools such as collaborative communities dramatically affects players' relationship networks. In this paper, we focus on networks. Furthermore, we show that OI diversifies the networks used in NSI.

3.12. Networks used in NSI

It is well known that one of NSI's most distinctive features is the numerous interactions among its components. Bearing in mind the importance of networks in NSI, pioneering researchers in this field consider NSI to be the network driving knowledge generation, diffusion, and use [15]. However, as several authors have shown, NSI networks only focus on formal knowledge exploration [90,91]. Typical examples of these networks are producer–user relationships and the triple helix of university–industry–government.

Producer–user relationships marked the birth of the term 'National System of Innovation'. In the 1980s, the strong producer–user relationships in the competitive Japanese manufacturing sector and Japan's resulting economic boom attracted the interest of scholars and policy-makers alike. In 1988, Lundvall claimed that research should focus on NSI instead of single producer–user networks. Focusing on the growing phenomenon of 'centres of excellence' where industrial development seems to be closely linked to the best universities [92], Etzkowitz et al. [39] coined the term 'triple-helix relations' to describe relations between university, industry, and government. Here, they stressed the role universities play in technical innovation and knowledge-based economies.

Such networks are popular in NSI research. However, many scholars have noticed that even when they include other types of networks, NSI research remains focused on the knowledge exploration phase and on formal players such as firms, universities, and government research entities [93]. In general, current research ignores the new forms of innovation networks, such as the growing online social networks and other collaborative communities for knowledge exploration [36,94]. Moreover, little work has been done on downstream networks exploiting existing knowledge [91].

3.13. Online social networks: Enlarging the knowledge exploration landscape

The OI model stresses the importance of using a broad range of sources for innovation and commercialisation activities by firms. Its success therefore mainly depends on the continued supply of external sources [3]. This supply of external knowledge can be sourced from traditional partners such as universities, users, and suppliers, as well as a range of other institutions and individuals. The knowledge they bring (often in the form of 'tacit knowledge') is a key asset in NSI. Therefore, the ability to locate, identify, and acquire valuable knowledge and generate various channels of knowledge transfer is of vital importance in a knowledge society. Online social networks are frequently used by firms as one of these channels but NSI scholars have not heeded them enough to date [95].

An illustrative case of online social networks is the trend towards open source software [71]. An oft-given example is the Linux Foundation. Open source involves collaboration between firms, suppliers, customers, and policy-makers of related products to pool software R&D and generate shared technology. Instead of the traditional extrinsic motivations, external innovators have strong intrinsic motivations such as reputation, fame, intellectual challenge, fun, and interest [72]. More recently, various online communities and hosted service webs facilitating co-operation and knowledge-sharing among innovating firms, customers, and other interested parties, have been recorded in the literature [94,96]. Social online networks, such as open source software communities, offer valuable benefits for society by encouraging community members to share their knowledge.

One way for policy-makers to elicit social knowledge is by building a wide range of internet-based platforms to bridge business sectors and create a broad range of knowledge, expertise, and skills in cyberspace. The power of this type of network lies in mobilising dispersed local knowledge that can be applied to both problem-solving and problem-seeking. The result is a more open-ended, fertile innovation process. Online social networks may solve problems for current business development or pool ideas [97] for future business development. Incentives can be either extrinsic, intrinsic, or both [72]. In this way, highly-skilled retirees, graduate students, professional workers in various disciplines, ordinary citizens, and research-based and profit-seeking organisations are linked up in online social networks. Individuals are carefully assigned to certain communities, for example, those serving a given sector. These communities are then tasked with innovating in a given knowledge field. Community members share the right to use and collaboratively develop certain technologies. Usually they work for free to pool solutions, experience, ideas, and other key knowledge for the business development of a firm [98,99].

3.14. Knowledge exploitation networks: Focus on commercialisation

Research has repeatedly shown that innovation is a multi-stage process. It consists of several critical stages, of which research and development and commercialisation are the most commonly cited ones in the literature [100]. However, the fact is that most innovation policy efforts focus on R&D progress rather than commercialisation. Open innovation stresses that a firm's business model acts as a filter, leaving just a few technology projects in the running for commercialisation. The upshot is that technological developments do not automatically lead to the successful launch of products and services [101]. More importantly, considerable efforts may have to be put into commercialising the unused technology through spin-offs or through licencing to other companies in other markets. As such, commercialising technology is a complex process, involving different parties such as users, suppliers, rivals, and other partners in the value network [3,36,102]. As March [33] noted, knowledge exploitation networks are entirely different from those covering universities and research-based knowledge-seeking organisations.

While the insights gained by knowledge exploitation networks have received less attention in the NSI literature, they are crucially important as they are directly responsible for the market success and profitability of new technologies [16]. OI may provide a new way to bridge this gap. For instance, Vanhaverbeke et al. [103] consider one of these exploitation networks by using the concept of value constellation. They suggest that value constellations differ from R&D networks insofar as they commercialise innovations with partners that have the wherewithal to bring the product or service to market [104]. In addition, exploitation networks commonly embrace complex network governance — something that is in sharp contrast with the dyadic relations between single partners that are typically found in knowledge exploration networks [105]. Scholars have therefore suggested that firms must set up and lead an entire value network to support their specific innovations [80]. Although research on this issue is still at an early stage, it is foreseeable that exploitation networks will grow in popularity over the next few years due to the growing reliance on OI. The emergence of exploitation networks will affect NSI as companies with promising, game-changing innovations set up these new kinds of (value) networks. An NSI can thus shift away from the link between research and educational institutions to focus instead on the commercialisation networks needed to launch new products. The government can play an important role in these networks. The growing importance of sustainability goals in the energy, car manufacturing, and chemical industries illustrates the changing role of governments in NSI today.

4. Conclusions

It may be unwise to limit the study of open innovation to the firm level. Companies are embedded in networks, industries, and national economies. In this study, we examine how open innovation practices in firms have an impact on the regional or national systems of innovation (NSI). An NSI is likely to be affected when companies change their innovation practices and the way in which they collaborate with external innovation partners. Surprisingly, the impact of OI practices on NSI has so far received scant attention from both scholars and policy-makers — a notable exception being De Jong et al. [7]. Making the connection between OI practices at the firm level and their impact on the meso- or national scale is hampered by the different theoretical approaches found in NIS literature, namely the structural, functional, and effectiveness approaches. The various perspectives put forward by these approaches have yielded a sufficiently detailed picture of NSI to study the impact of open innovation. As such, we have developed various arguments to demonstrate that companies' OI practices influence an NSI in different ways.

First, OI *reinforces the importance of NSI* more than ever. There is currently pressure to boost the effectiveness of technology markets given that innovating firms are increasingly interacting with other NSI partners. Similarly, the role of innovation networks becomes more important as a result of firms' OI practices. The locus of innovation no longer lies in single firms but in the innovation network [106]. Next, increasing inter-organisational knowledge flows raise the importance of having a reliable IP protection system. Companies work more and more on technology applications rather than on fundamental research. This is why the latter may need to be funded in new ways. Finally, OI hinges on the supply and mobility of highly-skilled knowledge workers. Hence, education and training need to be closely linked to innovation policies.

Second, OI provides several mechanisms to *improve the effectiveness* of NSI. This effectiveness can be enhanced by eliciting more resources for innovation. Besides private and public investments in R&D we also need to include a vast range of social resources that could be used in OI. Examples of such resources include: retired skilled workers; internet-based communities; innovation intermediaries. Next, NSI effectiveness can be boosted through greater labour specialisation in the innovation field. Finally, NSI will be more effective when the unused technologies of large companies are commercialised through spin-offs or when they are made accessible to other firms through licencing.

Third, OI leads to the emergence of many new structural elements such as innovation intermediaries and technology markets. To a great extent, OI will simultaneously diversify the networks used in NSI by creating two new types of networks: online ones fostering knowledge exploration, and exploitative ones targeting knowledge commercialisation.

As we mentioned earlier, these insights may have important policy-making implications. First, policy-makers need to realise that the rapid proliferation of firms' OI practices is changing the way companies innovate. Since IP ultimately rests on the activities and initiatives of companies, it is vital that policy follows this trend to foster a more open innovation environment. We have shown in this study how firms' OI practices influence the NSI and that policy-makers need to examine how their decisions can foster and speed up OI practices. First, the government can help by encouraging firms to work together in multi-partner innovation networks. Second, policy-makers are advised to broaden the scope of innovation to include not only joint research but also joint development and commercialisation activities. Third, policies may need to find new ways for improving NSI effectiveness by considering the roles played by innovation intermediaries and newly-emerging technology services facilitating open innovation. Fourth, more attention might be paid to the IPR system: it needs to be reliable and affordable for (smaller) innovators and policy-makers may need to stimulate the dissemination of unused knowledge. This requires a new policy towards large companies that hoard technology without using it. Fifth, governments can: (i) promote the generation and dissemination of high-quality knowledge; (ii) foster and support institutions channelling human and financial resources towards promising technologies and business models; (iii) highlight the reworking of good ideas through suitable business models and highly-efficient markets for technology and knowledge workers. Sixth, policy-makers may need to move away from funding innovation in single firms and towards networks of firms (given that this is the locus of innovation today).

Our study is broad in scope and examines how emerging corporate OI practices have an impact on the functioning of the NSI. Chesbrough et al. [4, p. 287] stated that “OI is practiced within the context of a given set of political and economic institutions, including regulation, intellectual property law, capital markets, and industry structure”. We have focused on the impact of corporate OI practices on the NSI. Even so, we only provided a general picture and did not tackle a given research issue. We encourage future researchers to delve more deeply into the links between OI practices and the NSI. In particular, we advocate studies on the link between corporate OI practices and: the education system; technology and business networks; IPR system; industry structure; regulatory system; funding rules for innovation. Empirical, comparative analyses of NSI in various nations could be one way of discovering which OI practices influence the NSI and how particular NSI features shape firms' OI practices.

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