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Global Innovation Systems – towards a conceptual framework for systemic innovation conditions in transnational contexts

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1. Introduction

In a globalizing knowledge economy, the mobility and circulation of people, information, knowledge, and capital increasingly interconnects innovation processes in distant places (Corpataux et al., 2009). As a result, clusters and territorially defined innovation systems become nodes in the global innovation networks of varying sectors. This increased spatial interdependency raises the question whether a territorial (local, regional, national) system perspective is still a valid one as system boundaries get increasingly blurry and porous. More fundamentally, one might argue that the innovation system (IS) perspective per se, on a more general level, is no longer a promising line of research and should be left on the shelves of the history of innovation studies, as concluded in the 2013 debate at the DRUID conference. The present paper argues against this view.

We maintain that a systemic perspective on innovation can still have considerable explanatory potential, not the least when adapted to increasingly multi-scalar and transnational innovation processes. However, to realize this potential, a number of conceptual improvements are required. The strong reliance on institutional structures that condition innovation in regional and national systems needs to be combined with greater emphasis on the role of multi-scalar networks and actors’ influence on institutional conditions. This calls for a more integrative view in which various existing innovation system perspectives and related literatures on the globalization of innovation and production start talking to each other in a more engaging and reciprocal way.

Innovation system studies emphasize that new technologies emerge from complex interactions between actors with complementary (technological, managerial, investment or regulatory) competencies, which operate under specific institutional settings. Calling these constellations innovation ‘systems’, emphasizes the distributed, yet more or less coordinated, configuration of
actors, networks and institutions in the innovation process. The system metaphor underpins the assumption that these interactions create positive externalities (later called system resources) that are of key importance in the innovation process, but very difficult to be produced or controlled by any actor on its own.

Over the past 20 years several concepts have been developed to understand the complex interactions and to predict innovation success by the way in which specific resources for innovation emerge from interaction in IS. In much of the early empirical work on national and regional IS, however, system approaches were portrayed as mostly providing ‘lists of relevant organizations and institutions’ and therefore being limited to mostly descriptive or comparative types of analysis (Uyarra and Flanagan, 2010). We maintain that this is a too restrictive interpretation of the explanatory potential of the IS framework.

To elaborate on this proposition, we take a closer look at the challenge of increasing globalization of innovation processes. Over the last decade authors argued that in various sectors’ innovation processes, non-territorial forms of cognitive, organizational, social, and institutional proximity are increasingly substituting for geographic co-location (Amin and Cohendet, 2005; Boschma, 2005). The geographical configuration of innovation systems is accordingly getting more complex, spanning actor networks and institutional contexts at various places and across spatial scales (Bunnell and Coe, 2001; Carlsson and Stankiewicz, 1991; Coe and Bunnell, 2003). While various analytical approaches conceptualize the increasing importance of transnational linkages between regional and national innovation systems to some degree (for an overview see e.g. Carlsson, 2006; Grillitsch and Trippl, 2013), a more comprehensive analytical framework for global innovation systems is still missing. In particular, existing concepts were criticized for remaining rather vague in their conceptualization of interdependencies between various territorial subsystems at an international level (Binz et al., 2014; Coenen et al., 2012; Grillitsch and Trippl, 2013; Wieczorek et al., 2015; Wieczorek et al., in print).

The present paper aims to reposition innovation system approaches to address these new realities. It draws on existing IS approaches, but emphasizes the role of systemic interaction in transnational networks - as acknowledged in the literatures on global value chains (GVC), global production networks (GPN) or global innovation networks (GIN) (see Coe et al., 2004; Gereffi et al., 2005; Liu et al., 2013). Innovation system scholars recently endorsed the need for a more constructive engagement with these literatures (Lundvall et al., 2014) and emphasized that the sectoral and technological innovation system concepts in principle resonate with GPN/GVC/GIN views as they address innovation processes without setting a-priori spatial boundaries (Breschi and Malerba, 1997; Carlsson and Stankiewicz, 1991). This notwithstanding, much work in the technological and sectoral IS area is still focused on innovation dynamics in specific regional or national contexts or preoccupied with developing stylized typologies of innovation trajectories in various sectors, without highlighting the role of multi-scalar system structures for specific innovation processes.

In this paper we aim to provide conceptual foundations for a ‘global innovation system’ (GIS) framework. In particular, we aim at specifying how various ‘subsystems’ get created and integrated (or not) at a global system level through the mobilization and anchoring of system resources as well as the co-evolution of actor networks and institutions from various places. In this venture we build on existing multi-scalar perspectives on innovation systems (Bunnell and Coe, 2001; Oinas and Malecki, 2002), but elaborate two new conceptual dimensions. First, we define subsystems of a GIS not based on pre-defined territorial boundaries, but based on the actor networks and institutions that are involved in creating specific system resources (knowledge, market access, financial investment and technology legitimacy, see Binz et al. 2015) and follow the network and institutions
wherever they may take us (Coenen et al., 2012). Whether or not the actor networks and institutions in each of these dimensions fall within territorial (national or regional) boundaries, is treated as an empirical question (Binz et al. 2014). The performance of a system in developing and diffusing innovation depends not only on the existence of coherent subsystems that produce each of these resources, but also on the availability of appropriate ‘structural couplings’ between them. Structural coupling is attained if specific actors, actor networks or institutions span across or overlap between various subsystems, be this in a specific region or country, in a global non-governmental organization or a multinational company.

Second, we draw on recent insights from economic geography and neo-institutional sociology to explain sectoral differences in the spatial configuration of IS in various industries. Our framework differentiates between a technology’s dominant knowledge base - analytical vs. synthetic vs. symbolic (Asheim and Coenen, 2006; Asheim and Coenen, 2005) - and the economic system of valuation in which markets for the innovation are constructed - standardized products for global mass markets vs. specialized products depending on symbolic valuation in local contexts (Huenteler et al., 2014; Jeannerat and Kebir, 2016). Based on empirical illustrations from recently emerging clean-tech sectors, we illustrate how the spatial configuration and structural coupling of subsystems may differ between industries that produce standardized commodities with an analytical knowledge base (i.e. semiconductors, solar photovoltaic modules) and industries with a synthetic knowledge base that depend on institutional embedding for market diffusion (i.e. biogas, wind power). This creates new explanation of why in some industries national and regional innovation systems remain relevant, while in other sectors they become subject to increased international interdependencies. Policy interventions that target specific national or regional subsystem will accordingly have different spatial spillover effects depending on the overall configuration of the global innovation system.

These arguments will be elaborated as follows. We first discuss the gaps in existing IS literature relative to the role of transnational linkages. Section 3 combines these insights to a multi-layered concept of global innovation systems, focusing on subsystems and their structural couplings at a transnational level. Section 4 develops a taxonomy of GIS configurations in different types of industry and illustrates them based on recent IS studies in emerging clean-tech sectors. Section 5 discusses methodological challenges and outlines a broader research agenda that might be developed in the global innovation system field. We conclude by discussing policy implications and the framework’s wider contributions to economic geography and innovation studies.

2. Existing perspectives on innovation systems in transnational contexts

2.1 Global innovation systems
Over the years, different variants of IS have been formulated and applied empirically, including a national (Lundvall, 1988), regional (Cooke et al., 1997), sectoral (Malerba, 2002) or technological (Carlsson and Stankiewicz, 1991) approach. Essentially, the distinguishing feature of each framework lies in the way system boundaries are set, i.e. in determining which elements contribute to the generation of innovation-related resources and which ones do not (Bergek et al., 2015). The a priori setting of spatial boundaries in much of the empirical IS tradition has increasingly been criticized (Coenen et al., 2012). With the dispersion and disaggregation of production and innovation, system resources may emerge in specific national or regional contexts while being at the same time systemically interconnected across space in various sectorial or technological contexts (Markard and Truffer, 2008).
Since the introduction of national innovation system literature in the late 80ies, various authors thus tried to develop more global, international or multi-scalar IS perspectives (Archibugi and Michie, 1997; Bunnell and Coe, 2001; Carlsson, 2006; Niosi and Bellon, 1994; Oinas and Malecki, 2002; Pietrobelli and Rabelotti, 2009). Especially Oinas and Malecki (2002) provide a comprehensive conceptual approach on how innovation processes in various RIS complement each other in a global division of labor. Yet, by starting from a regional perspective they imply that regional subsystems are the key level in which system resources are created in GIS. As a result, they remain relatively silent on how exactly these territorially defined subsystems get interconnected at supranational levels. Also among other GIS scholars, agreement increasingly formed that both territorial and non-territorial networks and institutional infrastructures matter for innovation and mutually influence each other. Yet, there is no shared understanding or conceptualization on how they matter, where they matter, let alone whether they matter for all sectors and markets in the same way (Binz et al., 2014; Coenen et al., 2012).

To expand on some of these issues, we first propose to re-interpret global interdependencies in the innovation process by combining insights from various innovation system approaches. This is achieved by reassessing innovation system structure from a transnational perspective and introducing a process-based evaluation of resource formation at a system level. Second, inspiration is drawn from two key conceptual notions of GPN and GVC literatures, namely (societal/ cultural/ territorial) ‘embeddedness’ (Hess and Wai Chung, 2006) and ‘strategic coupling’ (Coe et al., 2004; MacKinnon, 2012), to conceptualize the complex spatial interplay of circulation and anchoring of innovation-related system resources. In the remainder we will first define the basic conceptual building blocks of innovation systems in transnational context and then move to a detailed discussion of embeddedness and coupling from a GIS perspective.

2.2 Re-thinking innovation system structure in an transnational perspective

The core structural element of innovation systems are the actors engaged in the development and diffusion of new technologies, the formal and informal networks they form among each other as well as the institutional contexts that regulate these interactions. Actors include firms, research organizations, government departments, NGOs and other intermediary organizations that contribute to the development and diffusion of innovation. Mostly, actors have been conceptualized as internally homogenous entities with clearly defined interests and pursuing coherent strategies with respect to the innovation-related objectives. Internal processes such as organizational learning have been much less in the analytical focus (Morrison et al., 2008). When extending the analysis to transnational contexts, actors have to be conceptualized not as atomistic agents per se, but as a “constitutive part of the wider network through which emergent power and effects are realized over space” (Hess and Wai Chung, 2006: 1196). This point applies most directly to multinational companies, but is equally relevant for other actor groups such as research and education organizations, professional and industrial associations, (international) non-governmental organizations, citizens’ movements or even regulatory bodies with global reach (Boli and Thomas, 1997; Gosens et al., 2015; Meyer et al., 1997).

Also our understanding of the relevant actor networks has to be reconsidered. The seemingly obvious distinction between networks at the regional, national and international scale becomes increasingly blurred (Coe and Bunnell, 2003). Firms may coordinate activities in various intra-organizational or extra-organizational networks and along a continuum of governance forms ranging from market exchange relationships, to network forms of inter-firm governance, to the full integration and direct ownership. GVC literature (e.g. Gereffi, 2005) identifies five distinct network
governance forms (i.e. market, modular, relational, captive and hierarchy) and specified the particular contextual conditions that lead to a stronger or weaker integration within a chain/network (Gereffi et al., 2005; Parrilli et al., 2013). Transnational networks are often a materialization of different geographic and non-geographic proximities that can be institutionalized to different degrees ranging from the full integration in a formal organizational context (hierarchy) to loosely coupled virtual and epistemic communities as in the field of software development (computer games, Wikipedia). They can be long-living and continuous such as international professional associations or topical and ephemeral such as conferences of epistemic of practice-based communities (Maskell et al., 2006).

Finally, also formal and informal institutions may influence actor behavior not only at regional to national scales, but achieve validity at a transnational or even global level (Drori et al., 2003; Meyer et al., 1997). Among the often-cited regulatory institutions in IS research are international policy regimes and treaties (Conca K. et al., 2006), as well as technology transfer mechanisms (for instance the clean development mechanism of the Kyoto protocol (Gosens et al., 2015)), that set important boundary conditions for innovation processes. Intellectual property rights (IPRs) are a specific form of a transnationally valid institution that is crucial to the functioning of many innovation activities (Auerswald and Stefanotti, 2012). But also cognitive and normative institutions can develop validity beyond specific territorial contexts in the form of technological paradigms, professional cultures, or dominant rationalities of world culture (Boli and Thomas, 1997; Drori et al., 2014; Drori et al., 2003; Strang and Meyer, 1993). Overall, in a transnational perspective, innovation systems are constituted by complex actor networks and institutional contexts that jointly support (or hinder) the formation and diffusion of novelty in spatially variegated ways. They are in many cases not reducible to specific territorial contexts anymore, but depend on actor strategies, networks and institutional dynamics that co-evolve between different parts of the world.

Innovation system scholars accordingly argued that the combinations of actors, networks and institutions that support or hinder innovation are almost countless and that alternative configurations of the system structure can still lead to similar performance characteristics in the overall innovation system (Bergek et al., 2008; Edquist, 1997). Scholars in the tradition of technological innovation systems thus recently proposed to extend the analytical focus beyond system structure to core processes (or activities in the system) as a means to assess system performance (Bergek et al., 2008; Hekkert et al., 2007). This process view promises closer identification of performance conditions and a more dynamic understanding of evolving innovation systems.

These core system processes consists of knowledge production and diffusion, entrepreneurial experimentation, resource mobilization, guidance of the search, market formation, creation of legitimacy, and creation of positive externalities (Bergek et al., 2008; Hekkert et al., 2007). This list has originally been derived from an extensive literature review and an inductive aggregation of empirical innovation system studies. Since, various empirical applications of this process approach have shown robust view on innovation system dynamics over different phases of development (Markard et al., 2015). As we have seen above, the different system elements become more complexly structured in a transnational context. As a consequence, we can also safely assume that the core processes will be based on spatially more complex system structures than what was found so far in empirical studies focusing on single country case studies (Binz et al., 2014). Finally, the process approach allows for defining key resources that emerge from interaction in innovation
systems – knowledge, market access, financial investment and technology legitimacy - and to analyze in detail their spatial manifestations (Binz et al., 2016b).

Summarizing our discussion, it becomes clear that global innovation systems may consist of different areas of dense interactions that are linked by specific transnational actors, networks and institutional contexts. This spatially open understanding of IS comes near to the core ambition of global innovation networks formulated by Ernst (2002), namely to assess “how the combinations of concentrated dispersion with systemic integration determines the emergence of new opportunities for transnational knowledge diffusion and adoption”. A GIS approach goes beyond this view by encompassing non-knowledge based activities like market formation, investment mobilization or the creation of technology legitimacy. This leads to the need to develop a layered understanding of global innovation systems. Table 1 summarizes the core elements and processes of the IS framework and how they have to be reinterpreted in a transnational context.
Table 1: Extensions of conceptual components of IS in transnational context

<table>
<thead>
<tr>
<th>System elements</th>
<th>System dimensions</th>
<th>Conventional interpretation</th>
<th>Conceptual extension in transnational contexts</th>
</tr>
</thead>
<tbody>
<tr>
<td>System resources</td>
<td>Actors</td>
<td>Largely atomistic entities, with a high degree of internal strategic coherence</td>
<td>Multi-locational organizational entities, with quickly shifting shapes and boundaries. High potential for internal strategic variety and conflict</td>
</tr>
<tr>
<td></td>
<td>Networks</td>
<td>Mostly eye-level, collaborative exchange relations (knowledge, resources) between atomistic actors</td>
<td>Differentiation between actors and networks becomes blurry. Networks as materializations of different forms of proximity. Explicit consideration of asymmetric power relations in networks, modes of network governance</td>
</tr>
<tr>
<td></td>
<td>Institutions</td>
<td>Rules of the game to which all actors in a given territorial context are similarly exposed</td>
<td>Institutional structures have different “reach” socially and spatially. Dominant cognitive frames may reach global validity through the activities of international NGOs, expert communities or multinational companies</td>
</tr>
<tr>
<td></td>
<td>Technological knowledge</td>
<td>Mostly exchange of explicit and tacit knowledge among different actors. Diffusion channels rather underspecified or then linear transfer from knowledge producers to knowledge adopters</td>
<td>Globalized networks with territorially or socially densified areas. Diffusion into different regional contexts, absorptive capacity, interaction with NIS and RIS structures (P&amp;R2011). Differentiation between pioneer and latecomer regions/countries wrt TIS development.</td>
</tr>
<tr>
<td></td>
<td>Financial Investment</td>
<td>Strong emphasis on resources provided by national or regional governments, or jointly mobilized resources by actors in networks</td>
<td>Globalization of the finance industry, global movement of labor and expertise, emerging international attention of national innovation policies (e.g. export risk insurance, lead market strategies, development cooperation, etc.)</td>
</tr>
<tr>
<td></td>
<td>Market access</td>
<td>Niche markets mostly induced by national deployment policies</td>
<td>Social construction of markets, globalization of demand structures, diversity of customer preferences, globalization of niche processes</td>
</tr>
<tr>
<td></td>
<td>Technology legitimacy</td>
<td>Strong emphasis on national political processes, public discourses and the like Negotiations with local NGOs and other interest groups</td>
<td>Bargaining with non-company actors, NGOs and other intermediaries as increasingly global actors able to connect processes in different territories</td>
</tr>
</tbody>
</table>
3. Layered system structures and processes in Global Innovation Systems

From the analysis elaborated so far follows that in transnational contexts, two new conceptual elements have to be introduced: subsystems\(^1\) of a global IS in which specific system resources get formed and structural couplings between them. In the following, we will elaborate the new elements and propose a heuristic for assessing their configuration in transnational contexts.

3.1 Subsystems and structural couplings

In nationally and regionally delimited application of the IS framework, positive externalities for the innovation process were assumed to emerge more or less uniformly within a given national or regional territory. Also work on international or global IS continued arguing that regional or national levels provide the key contexts in which positive externalities form. GIS were accordingly seen as a set of interconnected regional subsystems that fulfill complementary roles in a global division of (innovation related) work in a technological trajectory (Oinas and Malecki, 2002). In our perspective, this seems to be a simplification. Giuliani and Bell (2005) and Giuliani (2007) have pointed out that knowledge resources in regional clusters are available in a highly selective and uneven way, also at the regional level. This pattern is found to be related to the heterogeneous and asymmetric distribution of local firms’ knowledge bases. When adopting a transnational view and considering not only knowledge-based resources in the strict sense, this asymmetry gets further intensified.

The question of “where” positive externalities get formed and which actors can get access to relevant system resources therefore should be addressed more explicitly. For this purpose, we propose introducing the concept of subsystems not in a spatially pre-defined way, but as those actor networks and institutional contexts of an innovation system through which specific system resources emerge. Subsystem boundaries can correspond to national or regional borders, but they may as well develop in multi-scalar networks that transcend national and regional borders. An example of a subsystem developing “at a global level” is legitimacy for a specific agricultural produce that is constructed by the interaction between globally active NGOs, a transnational company, and farmer’s collectives as in the case of fair trade labels. Other examples of relational, not necessarily territorially bound, externality formation processes are those created by specific actor networks, communities of practice and distributed forms of organizational, social, cognitive proximities. An iconic example are communities in the open source software field, where actors are not spatially collocated, but develop shared cultures, knowledge stocks and investment models that are hard to copy and access for outsiders. A similar example is knowledge creation in the membrane bioreactor field, which initially emerged from a global innovation network spanning engineers in French transnational water companies and research institutes in various places around the world (Binz et al. 2016).

As key system resources may develop in functional subsystems with very specific geographies, the overall development of a GIS will depend on whether and how the resource formation processes in various subsystems are coupled to each other. Our conceptualization of coupling relates to the notion of strategic coupling in GPN literature (Coe et al., 2004; MacKinnon, 2012), but diverges from

\(^1\) In similar vein, the RIS approach draws explicitly on the notion of sub-systems (Asheim and Gertler, 2005) through a distinction between knowledge exploration and knowledge-exploitation. In our paper we draw on this logic but seek to provide a higher degree of granularity in terms of sub-systems.
it in several respects. We explicitly relate ‘structural coupling’ to the foundational elements of an IS - be it actors, networks or institutions (see Bergek et al., 2015). Examples of coupling domains could be an internationally active firm that is able to assess knowledge resources from a specific regional innovation system and connect them to market segments in distant places. An example of institutional couplings is given by professional cultures (e.g. of engineers or technology consultants), which enable the formulation of globally shared technology standards and by this enable economies of scale to be reaped in different markets. Network coupling might happen at international conferences and trade fairs, where knowledge and information from different subsystems of the GIS get exchanged and recombined (Maskell et al., 2006).

In GIS, governance systems and power differentials between actors are accordingly multi-polar, fluid and subject to intensive contestation and negotiation processes. As key resources are distributed among various subsystems around the globe, actors in the GIS will in many cases not be able to directly appropriate a dominant share of them in-house, but will have to create strategic alliances and rely on non-geographic types of proximities to access and anchor the relevant resources (Binz et al., 2016b). Concentrations of innovative activity will accordingly develop in hubs where the actors involved in resource formation activities of different subsystems (e.g. knowledge creation, market formation, investment mobilization and legitimation) meet and interact (Binz et al., 2014). In some cases, these hubs may be territorially confined, in other cases they may develop temporarily at international conferences and trade fairs (Bathelt et al., 2004), or emerge from the international networks of TNCs or global NGOs. Resourceful actors with a global reach (such as TNCs, global donor organizations or professional and industry associations) might facilitate effective hubs, but they might as well emerge in a specific region with very dense personal and inter-organizational networks and experimentation activities, or even from a loosely coupled community of traveling technology experts (Larner and Laurie, 2010).

3.2 A multi-layered representation of global innovation systems

Summarizing the discussion, externality formation and structural couplings may give rise to a host of multi-layered topologies of system structures, compared to the geographically rather ‘flat’ representation of system structure in the NIS and RIS tradition. We may therefore conceptualize a global innovation system as being constituted by overlapping subsystems that provide essential resources for the overall maturation and diffusion of a technological innovation.

Figure 1 provides an illustrative mapping of an ideal-type GIS, which consists of interconnected subsystems exhibiting systemic interdependencies at different levels (national, regional) and in specific parts of the value chain. The major domains in which the subsystems exhibit hard-to-copy positive externalities are given in brackets. The figure consists of different (coupled) layers of subsystems, which generate resources for overall system maturation. In our example, on a first layer, actors with global reach (TNCs, globally active research institutes, standardization bodies, consultancies and international NGO’s) interact to ascertain the ‘mobilization of financial investment’ (GIS [fi]). An example could be an initiative by the Bill and Melinda Gates foundation, which provides funding for a consortium of transnational companies and leading universities in order to tackle a pressing public health issue, like AIDS. A second layer is constituted around the process of knowledge creation, which is here strongly related to the standard setting bodies and specialized (biotechnology) research institutes in a specific NIS (NIS,[kp]). Structural couplings may be provided through international collaborative research programs and the integration of various national standard
setting bodies in the technology standardization committees of the World Health Organization. A third layer is provided by a regional technology cluster which provides a supportive institutional environment for entrepreneurial experimentation (e.g. for advanced vaccination technology, (RIS$_j^{ex}$)). Structural couplings may be present through the fact that a TNC owns a branch plant located in the RIS and actively contributes financial investment and knowledge to local innovative milieu. The fourth and non-territorically bound layer is provided by specific market segments (MS$_2^{mf}$) in well renowned high-end test markets in university hospitals in different cities around the world, where learning about market needs and user response take place and thereby further increase legitimacy for the products (MS$_2^{le}$). Structural coupling among the various subsystems of the GIS is also provided by pharmaceutical companies collaborating with a consultancy firms to set up a strategic market deployment strategy. Success of the GIS will now not only depend on the quality of the different innovation processes that take place in specific parts of the world, but on the ability of key actors to couple these dispersed activities into a coherent innovation trajectory at a global level.

The global innovation system will perform well (here: develop a cure for AIDS) if different subsystems are well established and interconnected and thus able to mobilize and re-combine system resources for the development and diffusion of the innovation in focus. A key challenge is to overcome structural and functional ‘system failures’ (Weber and Rohracher, 2012) both in specific subsystems and in the way they are coupled internationally. Besides the system failures presented in the literature so far, our perspective adds a ‘transnational coupling’ failure for cases in which well-performing subsystems are not integrated effectively to a coherent GIS.

Figure 1: Generic structure of a multi-layered global innovation system.

Abbreviations in square brackets refer to different core processes (kp = knowledge production; ex = entrepreneurial experimentation; le= legitimacy formation; mf = market formation; rm = resource mobilization; gs = guidance of search). Systemic externalities are represented at the level of national (NIS) at regional innovation systems (RIS), and for a specific market segment (MS). The different actor types are given in the solid line circles (RO = research organization; TNC = transnational company; Cons= Consultancy; MTSQ = standard setting body; NGO = Non-governmental organizations)
4. Towards a dynamic perspective on GIS evolution

As many authors in innovation studies and economic geography pointed out, the structure of a GIS cannot be examined from a static perspective, but needs to account for the dynamics over the course of technology and industry maturation (Castellacci, 2008; Malerba, 2002; Pavitt, 1998). In the following we thus introduce a typology of ideal-type GIS configurations and hypotheses on how they may evolve over time depending on core characteristics of a given industry.

Our typology of GIS configuration starts from insights provided by the sectorial systems and the industry lifecycle literature (Abernathy and Utterback, 1978; Dosi and Nelson, 2013; Klepper, 1996), which focus on core characteristics of the new technologies that develop in a given industry. However, we extend this view by following (Jeannot et al., 2016: 277) in their critique that industry life-cycle scholars have “analyzed in ever more complex ways the endogenous knowledge processes driving economic change in production, but have usually left aside the question of how this change is endogenously valued in and related to market construction”. This point is especially relevant for an encompassing understanding of GIS, as we propose to explicitly analyze the co-evolution of a technology and its institutional embedding. As the corresponding alignment processes may depend on the availability of a wide range of sub-systems it would be insufficient to look at conditions for technological innovation alone. In fact, IS scholars have from the beginning emphasized user-producer interaction as a constitutive element of systemic innovation processes (Freeman, 1987; Lundvall, 1988). In order to introduce a typology of GIS structures and dynamics, we therefore distinguish in the following between two fundamental dimensions that shape industry dynamics: (technological) innovation and (product) valuation. The former concept refers to conditions for generating new variants of knowledge depending on specific characteristics of a technology. The latter emphasizes the pre-conditions for successfully embedding new products in specific contexts. Both dimensions will be scrutinized with regard to whether one would expect strong localized externalities to emerge or whether once established, the resulting socio-technical configurations can easily be replicated in other contexts.

4.1 Distinguishing GIS with analytical and synthetic knowledge bases

Relating to the characterization of industries with respect to technological innovation, we can build on an established literature in economic geography on the localized character of technological knowledge production (Doloreux, 2002). Authors like (Asheim et al., 2007; Herstad et al., 2014; Martin and Moodysson, 2013) distinguish between what can be broadly conceived as science-based industries with an analytical knowledge base (i.e. biotechnology, pharma, solar PV) and engineering-based industries with a synthetic knowledge base (car manufacturing, shipbuilding, wind power). Industries with analytical knowledge bases depend on knowledge that develops from the application of scientific principles and which can get codified in models, patents and reports. Formalized R&D inside the company, tight industry-university linkages and repeated radical technology breakthroughs characterize these industries. As knowledge can relatively easily be codified, knowledge exchange in internationalized networks, e.g. in scientific communities or international professional networks plays an important role (Asheim and Coenen, 2005; Martin and Moodysson, 2013). Production-related activities in industries with analytical knowledge bases will accordingly depend on significant spillovers beyond regional and national borders (Moodysson et al., 2005). We thus expect the innovation-related subsystems of a GIS to develop in complex, multi-scalar networks that transcend various regions and countries.
Industries with a synthetic knowledge base (car manufacturing, shipbuilding, wind power), in contrast, base innovation more strongly on novel recombination of experience-based knowledge and competencies (Martin and Moodysson, 2013). Technological knowledge is not predominantly developed through scientific abstraction, but rather through on-the-job training, as well as learning by doing, interacting and using. Formalized R&D is less important, as new combinations are developed in solution-oriented producer-user interaction. In this more incremental way of learning, tacit knowledge embedded in craft and practical skills is of high importance (Asheim and Coenen, 2005). The innovation-related processes in a GIS accordingly tend to generate strongly localized externalities because continued face-to-face interaction facilitates learning, tacit knowledge circulation and informal exchange, which gives rise to specific territorial subsystems (Martin and Moodysson, 2013). Accordingly, the GIS structure in industries characterized by synthetic knowledge will be characterized by subsystems which emerge out of spatially concentrated actor networks that are deeply embedded in specific region’s historically grown institutional contexts.

The second differential dimension relates to processes of valuation of new product variants. In some industries, products and technologies may be almost indistinguishable. For instance, markets for mass-consumed goods like detergent, shampoo or cellphones look similar all over the world. However, in various modern industries with more complex end products, the valuation by end-users requires a broad range of proactive social construction and social embedding processes. In these cases the relative importance of technological characteristics may be less decisive for the overall success of the innovation. In the extreme, we may think of industries where the management of valuation processes is overwhelmingly important while technological advances may be neglected. In economic geography, valuation competences have been strongly associated with ‘symbolic knowledge’ (Martin and Moodysson, 2011). Here, cultural awareness about latest fashion and design trends and informal knowledge from various ‘underground’ communities rather than formalized R&D plays the key role for innovation success (Bathelt and Cohendet, 2014; Martin and Moodysson, 2011). Innovation in this realm emanates from highly place-dependent communities (Martin and Moodysson, 2013) which have a deeply contextualized understanding of contemporary cultural trends (Grandadam et al., 2013).

4.2 Distinguishing GIS with standardized mass products vs. institutionally embedded products

As a general differentiation, we may identify industries with standardized products and distribution channels (consumer goods, raw materials, solar PV) and industries where specialized markets are co-produced between suppliers and consumers in institutionally embedded interaction (luxury goods, creative industries, wind power) (Abernathy and Utterback, 1988; Davies, 1997; Huenteler et al., in press; Jeannerat and Kebir, 2016). In the first case of “standardized mass products”, consumption processes are stabilized around clearly identified goods, services and producers (Jeannerat and Kebir, 2016). End-users have relatively undifferentiated demand structures that are uniform in various parts of the world and base their acquisition choices mainly on price signals. Demand articulation, marketing, and sales are relayed through specialized market research organizations, and user demand can be served by standardized distribution channels (ibid.). Once a mass market has formed, it thus constitutes a system resource to which actors from all over the world have access, as they can supply it with standardized products without much need for adaptation to specific regional contexts. Valuation processes in industries with standardized mass products can accordingly be described as relatively ‘footloose’; globally valid dominant designs and quality standards will equally influence
innovation dynamics in various parts of the GIS. Valuation-related functional subsystems of the GIS (market formation, legitimation) can accordingly be expected to develop in highly internationalized actor networks and institutional contexts (as facilitated e.g. by TRIPS and the WTO).

In contrast, in industries that depend on ‘institutionally embedded products’, innovation success relies more strongly on symbolic knowledge bases as new products have to be institutionally embedded and legitimized in specific territorially confined market places. Products need to be tailored to the needs of specialized user groups or depend on symbolic embedding in specific historically grown territorial contexts (luxury cars from South England, Swiss watches) (Jeannerat and Kebir, 2016). New market segments need to be constructed in a complex negotiation process in which users and producers attach specific symbolic meaning to a new technology or product (Jeannerat et al 2016). The design and branding of products get incrementally adapted based on shifting user needs, changes in the wider institutional context, or new technological opportunities. Innovation, marketing and sales strategies accordingly rely on various types of institutional entrepreneurship which aligns consumer’s normative and cognitive associations with specific types of technology (Binz et al., 2016a; for an overview see Huenteler et al., in press; Jeannerat and Kebir, 2016). In industries with institutionally embedded products, market creation in one specific region of the GIS does not automatically imply that a system resource is created that is easily accessible for actors in other places. To access such markets, outsiders would rather have to invest heavily in getting embedded into the user-producer networks and invest into a deep understanding of localized institutional contexts of a specific marketplace. Valuation-related subsystems (market formation, legitimation) in GIS with ‘institutionally embedded’ markets can thus be expected to rely on actor networks that are strongly concentrated in specific regions.

From these two dimensions, we may now construct a stylized typology of potential GIS structures (see figure 2). In general it will be difficult to precisely position an industry in the two dimensional graph. Most industries are characterized by specific combinations of analytic, synthetic and symbolic knowledge (Moodysson et al., 2008) and need to comprise a range of alternative valuation strategies. E.g. car manufacturing would be positioned close to the center of the x-axis as it depends on a mix of science-based technological improvements, experience-based engineering skills, and cultural trends and design preferences. Biotechnology would in turn be positioned closer to the analytical knowledge pole as it relies more heavily on scientific discoveries than on experience-based engineering. This notwithstanding, the positioning of specific technologies and industries should enable to predict whether the GIS’s subsystems and coupling patterns develop in a geographically rather flat (strongly internationalized), or complex multi-scalar configuration.
4.3 Illustration: GIS configuration in emerging cleantech industries

Figure 2 synthesizes the above discussion by schematically visualizing the spatial configuration of GIS in industries with varying knowledge bases and product valuation systems. Four ideal-type GIS configurations can be distinguished, which will now be discussed in more detail and illustrated with examples from the burgeoning literature on innovation system formation in clean-tech sectors.

I) GIS with analytical knowledge bases and standardized mass products: Solar photovoltaics

The first quadrant exemplifies the GIS of industries that are arguably subject to the highest possible level of global interdependencies among and between subsystems: As the relevant knowledge bases, investment mechanisms, market conditions and quality specifications can easily be codified and standardized, international networks and globally valid institutional frameworks will play a key role at both the technological innovation and valuation side of new products.

An industry that nicely illustrates this GIS-type is solar photovoltaics (PV) (also see Huenteler et al., 2016). Innovation in the PV industry depends on advances in analytical knowledge bases like material sciences or nanotechnology (Huenteler et al., in press; Peters et al., 2012), while the economic valuation of solar PV modules is organized in standardized, global mass markets (Huenteler et al., in press; Quiztow, 2015). System resources formation depended on specific territorial subsystems only for relatively short periods of time and in early life-cycle phases, e.g. when the pioneering companies in the USA and Japan created initial knowledge and technology legitimacy in 1970-1990 (Varadi,
2014), or when first mass markets were constructed in Germany between 1990 and 2005 (Dewald and Truffer, 2011; Dewald and Truffer, 2012). Yet, once these system resources had been created, outsiders and technology latecomers - most prominently from China - could mobilize and anchor them in their own industry formation process relatively easily (Binz and Diaz Anadon, submitted; Quitzow, 2015). Nowadays, all relevant subsystems in the PV field emerge from complex networks spanning several regions in developed and emerging economies and through the activities of actors with global reach (Binz and Diaz Anadon, submitted; de la Tour et al., 2011; Gallagher and Zhang, 2013; Quitzow, 2013). Structural couplings at an international level were repeatedly of key importance, e.g. when US and European investment banks organized IPOs for Chinese PV module manufacturers in the mid-2000s (de la Tour et al., 2011; Zhang and White, 2016) or when German suppliers of turnkey production lines started basing their innovation activities on close interaction with Chinese manufacturing companies and Australian universities (Dewald and Fromhold-Eisebith, in print; Quitzow, 2015). Also at the demand side, subsystems got increasingly coupled at an international level, i.e. when the World Bank and the international electrochemical commission (IEC) pioneered the development of globally harmonized quality standards and testing procedures for solar PV modules, which essentially harmonized market entry barriers in various parts of the world (Cabraal, 2004; Varadi, 2014).

III) GIS with analytical knowledge base and institutionally embedded products: wind power

The GIS configuration of industries in quadrant III of Figure 2 (i.e. wind power), directly contrast the case described above. This GIS type depends most strongly on subsystems and structural couplings emerging inside territorially delimited subsystems. The technological innovation side is dominated by complex ‘bricolage’ processes in which various knowledge stocks interrelate with experience-based skills and crafts (see Garud and Karnoe, 2003). Markets will equally not be globally homogenous, but show strong geographic variation in terms of specialized user needs, regulation, and levels of technology legitimacy. In this setting, global couplings are achievable only if strong and sustained pipelines are established between territorially deeply embedded subsystems of the GIS.

The early wind turbines industry perfectly illustrates this case. Wind turbine manufacturers strongly draw on a synthetic knowledge base (Garud and Karnoe, 2003; Huenter et al., in press), while market deployment depends on institutional embedding and regional technology legitimation, i.e. in places where organized opposition to wind parks emerges (Wuestenhagen et al., 2007). As expected by our framework, recent empirical case studies show that innovation processes in spatially clearly distinguishable subsystem - e.g. in the USA, the EU, and in particular Denmark – played a key role in steering the wind industry GIS from a long era of formation to a dominant product architecture (Karnøe and Garud, 2012; McDowall et al., 2013; Simmie et al., 2014; Wieczorek et al., 2015). Territorially embedded learning by doing and interacting and co-located actor networks with complementary knowledge in manufacturing and application (turbine manufacturers, farmer’s collectives, research and testing organizations, governmental intermediaries) initially facilitated the relevant system resources in only two countries – Denmark and the US (Bergek and Jacobsson, 2003; Garud and Karnoe, 2003; Karnøe and Garud, 2012; Simmie, 2012). Later on, activities emerged also in Germany as well as India and China, but structural couplings at a transnational level started to play a role only after a dominant turbine architecture had stabilized, and were constrained to the build-up of stable knowledge pipelines, e.g. through M&A and long-term technology licensing agreements between European and Chinese/Indian firms (Lema and Lema, 2012; Lewis, 2007; Lewis, 2011).
Nowadays, innovative turbine designs are still predominantly developed in a few countries that were involved in early industry formation and market deployment (in particular Denmark, Germany and the USA). Territorially delimited subsystems of the GIS thus retained considerable first mover advantages through later industry life cycle phases (Huenteler et al., 2014; Lewis, 2011; McDowall et al., 2013). This stands in strong contrast to the solar PV case, where ubiquitous coupling at an international level made the technology pioneers from the USA and Japan lose their initial supply and market dominance over a relatively short period of time (Binz et al., in preparation; Nahm and Steinfeld, 2014).

II) GIS with analytical knowledge bases and institutionally embedded products: CCS

The other two GIS types in quadrant II and IV can be considered variations of the two extreme cases just presented. Industries with analytical knowledge bases and institutionally embedded markets, depend on a GIS in which innovation-related subsystems transcend territorial boundaries, while product valuation depends on institutional embedding and legitimation in specific territorial contexts. Carbon capture and storage technologies (CCS)\(^2\) are a telling illustrative example here. Innovation at the supply side of this technology depends heavily on basic science in analytical knowledge fields such as geology or analytical chemistry (Markusson and Chalmers, 2013; van Alphen et al., 2010). Several studies reported considerable progress in the knowledge creation and investment mobilization subsystems of this field, with significant structural couplings at an international level through the activities of international research consortia and intermediaries like the International Energy Agency (IEA) or the Intergovernmental Panel on Climate Change (IPCC) (Markusson and Chalmers, 2013; Nykvist, 2013; Pickard and Foxon, 2013). Still, the high dynamism at the technology side of innovation is confronted with persistent (and spatially highly variegated) challenges in the valuation dimension. High-profile CCS programs in the US, Holland, Norway or China all struggle with missing technology legitimacy, unclear market prospects and other incompatibilities with the relevant regulative, normative and cognitive institutional contexts (Haarstad and Rusten, 2016; Nykvist, 2013; van Alphen et al., 2010). Even though technology proponents are continuously exploring ways to symbolically better embed CCS in specific regions, pilot projects still fail in spectacular and often highly context-specific political struggles (Haarstad and Rusten, 2016).

IV) GIS with synthetic knowledge bases and standardized mass products: electric cars

In industries that depend on standardized markets with a synthetic knowledge base (quadrant II, i.e. electric vehicles), finally, territorially embedded subsystems play a key role for technology innovation, while new product valuation can be organized in standardized mass markets. Territorially strongly embedded subsystems in specific (US, European, and Asian) regions with concentrated engineering, research and design competence have been a key factor for technological innovation in the car sector for decades (Dicken, 2007). At the same time, distribution channels and quality criteria got strongly homogenized globally, with user tastes gravitating around a few standardized product categories (ibid.). Innovation in this sector thus depended on coupling between regional innovation hubs and specialized distributors and market analysts operating at an international level. The emergence of electric cars now threatens to shake this well-aligned global GIS configuration: New

\(^2\) Technologies to filter CO2 from the exhaust of fossil fueled power or production plants and store it in underground geological formations or in the ocean.
entrants like Tesla or Google use IT technology and new media applications to valuate electric cars as a customizable and luxurious high-tech gadget (Jeannerat and Kebir, 2016; Wesseling et al., 2015). With this introduction of analytical and symbolic knowledge into the sector, we would expect the global GIS to gravitate more strongly towards a situation as described in the CCS case above.

4.4 **Industry lifecycles and GIS configurations**

This last example shows that the GIS framework’s explanatory power can be increased when applying a dynamic perspective on GIS evolution. The spatial configuration of GIS is not a given, but may change considerably over the industry lifecycle. More precisely, both the knowledge base and economic system of valuation may shift over time, i.e. when initially complex engineered products get standardized around a dominant design and develop into increasingly uniform commodities for global mass markets, as in the case of the solar PV GIS around 2008 (Dewald and Fromhold-Eisebeth, in print). Figure 3 illustrates other relevant shifts in the GIS configuration of the industries discussed above. The solar PV and on-shore wind GIS show equivalent lifecycle patterns in the valuation dimension; both industries initially emerged in institutionally strongly embedded niche markets and over time developed into increasingly standardized commodities for global mass markets. In the PV GIS, standardization is now highly advanced in the innovation and valuation dimension (Dewald and Fromhold-Eisebeth, in print; Quitzow, 2015). In the wind case, institutional embedding still plays a key role for supply-side innovation dynamics and in specialized market segments like off-shore wind turbines, while standard on-shore wind turbines developed into an increasingly standardized product with price-driven global market competition. In both cases, a significant transition in the GIS’s spatial configuration is thus observable after a dominant design or product architecture emerged (Huenteler et al., 2014).

Other GIS, i.e. in the field of electric vehicles, experienced significant shifts at the innovation side. Especially with the recent shift from traditional synthetic knowledge to more analytical and symbolic knowledge bases, a shift from spatially sticky territorial production subsystems and standardized mass products toward more internationalized couplings in production and regional variation of valuation strategies can be expected. Innovation in CCS technologies, finally, can be expected to develop in a relative stable GIS configuration outlined above.
5. Discussion: Outlines of a research agenda and key methodological challenges

The conceptual discussion and empirical illustrations above show that developing an operable global innovation system framework could constitute novel hypotheses on how systemic innovation processes in various regions, nations, and internationalized arenas interrelate. A vibrant research agenda with potentially highly relevant policy implications could be could be developed in this field if a variety of methodological challenges can be solved.

5.1 GIS – Foundations for a new research agenda

Overall, we posit that the GIS framework provides a rich foundation for future more empirically informed analyses. Its quality may ultimately be judged on whether it is able to generate new interesting research questions and testable hypotheses. As for the first challenge, we claim that several conceptual proposals for GIS that were recently formulated (among others Binz et al., 2016b; Dewald and Fromhold-Eisebith, in print; Fromhold-Eisebith, 2007; Gosens et al., 2015; Oinas and Malecki, 2002; Quitzow, 2015; Wieczorek et al., 2015) can be positioned in the presented framework and used to shed light on specific conceptual problems. As for the second challenge, we can here outline a – necessarily partial and incomplete – list of promising research fields that could be informed by this framework to develop testable hypotheses.

First, one could explore in detail for each GIS type how and where subsystems emerge, how subsystem formation processes differ between different types of regions and what type of system
resources get created where and how. Ultimately, a GIS view provides new perspectives on the conditions for the emergence of positive systemic externalities. Future work would have to discern in detail how interdependencies between heterogeneous actor groups lead to externality formation and beyond territorial boundaries and how access to these resources is organized and governed. More work is needed on the question how spatially dispersed communities of practice or temporary clusters may support and sustain the generation of system resources like knowledge, markets, financial investment, or legitimacy (Binz et al., 2016b). Also, depending on the industry in focus, different forms of proximity might play a crucial role in resource formation processes at a transnational level.

Second, structural coupling as a key process in innovation system formation should be further explored. How does structural coupling work in detail, what types of actors are important, and how do more informal structural couplings (i.e. at a cognitive institutional level) connect the activities in various subsystems of a GIS? One key set of research questions can be related to the role of system managers: GIS need a minimum of system coordination. As discussed above, our concept emphasizes that not only transnational corporations, but also other actor types like industry and professional associations, international NGOs, city networks, international donors, consulting firms, etc. can play an important integrative role. A deeper engagement with the literature on system intermediaries may be interesting here (van Lente et al., 2003). Also, the co-evolution of different subsystems in hubs could be explored in more detail: A key question is how knowledge creation, market access, financial investment and legitimation strategies get coupled at an international level? We have much knowledge on regional exchange platforms, but not so much on exchange mechanisms in temporary clusters, global epistemic communities and international NGOs (Coe and Bunnell, 2003; Maskell et al., 2006). Also, a key research agenda could be related to the anchoring of external system resources in specific regions and countries: How do system externalities that developed in international networks get anchored to specific local contexts and how does contextualized knowledge get up-scaled to global technology and market standards? And how does this process differ between industries? A delicate balance of external structural couplings and embedding in regional institutional contexts will be needed to connect innovation process at various spatial scales (Binz et al., 2016b).

Third and finally, an agenda that was downplayed to some degree in the above discussion relates to issues of power. GIS will likely not develop through harmonious cooperation, but rather be subject to permanent contestation and power struggles among interested actors. An improved understanding has to be developed on the type of actor constellations attain a structural superior position to influence innovation beyond regional contexts. How do power asymmetries in global network architecture influence how and where novelty is developed and diffused (or not)? Connecting IS approaches more explicitly to concepts such as network governance in GPN/GVC literature appears very promising here (Gereffi et al., 2005). Also, the role of powerful actors may be scrutinized in more detail: Structural couplings may at the one hand limit the room for maneuver of subsystems (due to actors having to accommodate different rationalities at the same time) but they are also essential for the mobilization of resources. This is especially important when incumbents enter an innovation system and try to influence the course of development. While resourceful actors might be particularly apt to manage transnational linkages, they might also induce tradeoffs between innovation and the potential for lock-in into well-established cognitive frames. As a consequence, the relative role of incumbents in GIS may be indirectly proportional to the disruptiveness of the
innovation in focus. Various connections to recent work in sustainability transitions literature and organization studies could be explored here (Fliedstein and McAdam, 2011; Geels, 2014; Lavie, 2006; Wesseling et al., 2015).

5.2 Methodological challenges

The multi-layered topology of GIS implies a set of formidable methodological challenges. Analyzing the activities of all actors that participate in a GIS and considering all the relevant networks and institutional contexts can quickly prove to be an overwhelming task. This is probably the reason why most IS studies still focus on single country or regional case studies. However, if the goal is to ultimately adapt the IS concept to opportunities and problems related to ongoing economic globalization, this challenge will have to be confronted. At least, this problem has to be tackled at the beginning of an innovation system analysis, when motivating the choice of the system boundaries (Bergek et al., 2015). Innovative methodological proposals have recently been formulated on how specific resource formation processes like knowledge creation (Binz and Truffer, 2012; Binz et al., 2014), market formation (Dewald and Truffer, 2012), creation of legitimacy (Markard et al., submitted), or entrepreneurial experimentation (Wieczorek et al., in print) can be analyzed beyond pre-set spatial boundaries. At the same time, the increasing quality of global databases on patents, publications, trade statistics or pilot plant experimentation may be exploited to define system boundaries in an empirically more informed way. Finally, recent advances in social network analysis and stochastic actor-based modeling might open new inroads to empirically delimiting and analyzing GIS subsystems and their international coupling patterns.

Ultimately, the choice of methodology should relate to the needs of the case analyzed. In many cases it may be defensible to conduct analyses in specific territorially defined subsystems of the GIS (Binz et al. 2014). For instance, if the most significant subsystems and structural couplings are located inside a given country or region (as was the case for early wind power in Denmark), nationally delimited IS analysis will cover the most relevant innovation processes of the respective GIS. The sector typology developed in section 4 might further inform the setting of system boundaries as it provides theoretical hypotheses on the geographic configuration of GIS in various industries. A global innovation system perspective may thus provide an encompassing heuristic for positioning partial IS analysis in specific countries or regions in broader sectorial and spatial contexts. It may also allow for a more causal understanding on how innovation processes in various industries develop over time and in space and on how policy making can influence the process.

5.3 GIS-based policy implications

The empirical illustrations discussed in section 4 imply that innovation dynamics are in many sectors not well aligned with conventional national to regional policy strategies. What sort of new governance approaches and institutions are needed to get to grips with dynamically evolving global innovation systems? We would expect those governments with a proactive and externally oriented analysis of industry dynamics to have a more robust industry strategy than the more parochial ones. The experience with the national feed-in tariff for solar PV in Germany in the early 2000s may serve as a case in point for a policy intervention that was not reflective of the basic characteristics and life-cycle dynamics in the industry’s underlying GIS configuration. When Germany implemented an ambitious national market deployment subsidy for solar PV modules in 2002, it aimed – among others - at creating a mass market that would provide the German PV manufacturers with a first-
mover advantage (Hopmann et al., 2014; Peters et al., 2012). Yet, given the ubiquitous international structural couplings in the solar PV GIS, this policy did not create sustained first mover advantages for the German panel manufacturers, but induced substantial spatial spillovers to various other subsystems of the GIS, in particular to China, Korea, Taiwan or the USA (Binz and Diaz Anadon, submitted; Dewald and Fromhold-Eisbith, 2015; Quitzow, in print). We here posit that the high spatial fluidity of this industry (which came as a surprise to German policy makers) could have been explained and predicted to some degree based on our analytical framework.

Developing innovation and industrial policies in specific countries more strongly on a well-developed GIS framework might accordingly avoid unintended spatial spillovers and enable more targeted support strategies for specific parts of an industries global value chain. It might also be used for identifying and eliminating system failures that inhibit the development of an innovation both in specific subsystems and the structural coupling patterns of a GIS. Based on our framework we would add a ‘global policy coordination failure’ which extends on Weber and Rohracher’s (2012) national policy coordination failure. E.g. in the solar PV case, uncoordinated national policy interventions resulted in global overcapacities, trade disputes and import tariffs which significantly lowered the efficiency of the GIS in diffusing this environmental innovation. Finally, GIS-based global governance systems could be designed that reflect a sector’s specific innovation and valuation characteristics and thus constructs more level playing field for all involved actors around the world.

As a final thought we posit that GIS approach based on subsystems and structural couplings offers a promising meso-level heuristic for developing new research hypotheses, as well as deriving explanatory insights on how system dynamics influence innovation and industrial change in various parts of the world. As such, rather than putting the IS approach into the shelves of the history of innovation studies, we encourage a renewed effort of dedicated research in this still promising and underexplored field.

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