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A Complexity-Theoretic Perspective on Innovation Policy

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Abstract: It is argued that innovation policy based on notions of market failure or system failure is too limited in the context of current societal challenges. I propose a third, complexity-theoretic approach. This approach starts from the observation that most innovations are related to existing activities, and that policy's additionality is highest for unrelated diversification. To trigger unrelated diversification into activities that contribute to solving societal challenges, government's main task is to organize the process of demand articulation. This process leads to clear and manageable societal objectives that effectively guide a temporary collation of actors to develop solutions bottom-up. The combination of a broad coalition, a clear objective and tentative governance are the means to cope with the inherent complexity of modern-day innovation.

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1. Introduction

With the fall of Keynesianism in the 1980s and the rise in global competition in the 1990s, innovation policy has become the cornerstone of economic policy in every high-income country or region. Indeed, since Solow's (1957) seminal study, ample empirical evidence has been collected showing that innovation accounts for a large part of economic growth. By stimulating innovation in firms, governments hope to increase productivity, employment growth and prosperity. Though the main objectives of innovation policy may be widely shared politically, the understanding of innovation processes in the economy, and how these can be influenced by policy, is ill-understood.

In this essay, I will first summarize the two dominant perspectives on innovation policy (the market-failure approach and system-failure approach), and I will then develop a more historical perspective based on complexity theory. While the complexity-theoretical perspective incorporates key elements from the two existing paradigms, it opens up a new perspective in which institutions are seen as co-evolving with radical innovation, rather than simply enabling incremental innovation processes. Using this framework, we critically assess Mazzucato's (2013) notion of the "Entrepreneurial State" and end with a plea for a more bottom-up, challenge-led innovation policy.

2. Market failure

Academic thinking about innovation, and innovation policy, has long been dominated by the economics profession. From the perspective of mainstream economy theory, innovation – defined here as the successful introduction of new products, services and production processes – can be viewed as a knowledge production activity. Similar to any kind of production activity, inputs are transformed into output where inputs are mainly knowledge and research equipment and output are new products and production processes. This linear view on innovation is well suited for econometric analysis once inputs are proxied by R&D expenditures and outputs by patents. Using such a "knowledge-production-function", one can measure the return to R&D investments at regional or national levels as well as the extent to which regions/countries benefit from R&D invested by other regions/countries, otherwise known as spillovers.

From the perspective of the linear model, the economic question holds whether the R&D investments is below the socially optimal level. Theoretically, it can be expected that firms under-invest in R&D because part of their outputs of their investments spillover to other firms, who imitate innovation without remunerating the originator, a case of market failure (Arrow 1962). This is especially the case in industries where innovations cannot be patented. Hence, the conditions that allow firms to appropriate the returns form their R&D investment are important. A second reason why firms may under-invest related to the inherent uncertainty, in the Knightian sense, of the outcomes of R&D investments. In many cases, firms cannot foresee at all whether R&D investment will lead to a successful innovation. Consequently, firms will find it difficult to raise funding. These theoretical arguments provide a clear policy rationale for R&D subsidies for firms as well as for universities, and for tight patent protection. Indeed, if firms invest less in R&D than that would be socially desirable, R&D subsidies and strengthening patent protection are standard ways to repair such market failures.

For long, R&D subsidies – mainly in the form of R&D tax incentives such as wage subsidies for R&D personal and lower profit tax for R&D performing firms – were uncontroversial given the strong theoretical support from economics and the strong political support from left to right given their shared objectives in promoting growth and employment. However, the more recent insights cast some doubts about R&D subsidies. First, the effect of R&D subsidies on private R&D investments is rather small. At the micro-level, a meta-study found that the elasticity is 0.21 meaning that if subsidies reduce the cost of R&D by 1 percent, firms only invest 0.21 percent more in R&D (Gaillard-Ladinska et al. 2015). There is also some evidence that this effect is even lower for larger firms. At the macro-level, there is no relation between a country's innovativeness and the share of government support to R&D that is allocated via R&D tax incentives (Gaillard-Ladinska and Straathof 2015). Furthermore, it may matter a lot how innovation is defined in the context of R&D subsidies. Some countries subsidize any R&D activity including innovations that are new-to-the-firm but have already been developed elsewhere, while others are more restricted and subsidize only firms who develop innovation that are new-to-the-country and new-to-the-world. In the former case, R&D subsidies may actually discourage true innovations to some extent, as governments subsidize firms to imitate innovations of others. In all, this suggests that restricting R&D tax incentives to smaller firms that developed new-to-the-world innovations would be most effective.

A second critique to the market-failure rationale for innovation policy focuses on the patent system. As stressed by Boldrin and Levine (2013), there exists a "patent puzzle": in spite of the enormous increase in the number of patens and the strength of their legal protection from the 1990s onwards, productivity growth has slowed down in almost all high-income counties in the same period. This suggests that patents may do as much good as they do harm. For example, many technologies that are patented are not exploited commercially; rather, these are patented to prevent competitors to enter into particular innovation paths. Furthermore, as a piece of knowledge can be both an output of one firm's R&D process and an input of another firm's R&D process later on, tight patent protection may block promising innovations, especially of the recombinant type. More generally, the importance of patents in stimulating innovation is should not be overstated, because firms dispose of other strategies as well to protect their innovations, including secrecy, branding and being first to the market (Arundel 2001; Cohen et al. 2002).

3. System failure

A second influential approach in innovation policy starts from the notion of a national innovation system. Freeman was first to introduce this concept, and defined it as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies (Freeman, 1987, p.1), where the word institutions here refers to actors such as firms, universities, financial organizations, public research organizations, government, consumer organizations, etc.. The concept of the "triple helix" of university-industry-government relations proposed by Etzkowitz and Leydesdorff (2000) also stressed the benefits of collaboration and coordination between actors. Both notions of innovation system and triple helix stemmed from the recognition that many innovation processes involve a multitude of actors who each contribute and jointly collaborate to the shaping and success of new technologies and services. In this more holistic perspective, the functioning of an innovation system can thus be assessed by looking for system failures in analogy to market failures. Such failures may refer to an underdeveloped actors within the innovation system or underdeveloped linkages between actors that make up the innovation system (Klein Woolthuis et al. 2005, p. 611).

The notion of system failure was already implicit in policy circles in the mid-1990s when the "European Paradox" was identified, which came to dominate European innovation policy thinking for at least 15 years. This paradox was formulated as: "Compared with the scientific performance of its principal competitors, that of the EU is excellent, but over the last fifteen years its technological and commercial performance in high-technology sectors such as electronics and information technologies has deteriorated." (European Commission, 1995, p. 5). The key to solving the paradox was to increase the interaction between the key actors in the innovation, identified as firms, universities and, to a lesser extent, financial organizations. This observation was the more important because it ran against the linear model – dominant at the time – because the paradox indicates that inputs, such as a strong scientific knowledge base, does not automatically leads to outputs, such as competitive advantage in new industries.

The notion of the European paradox, and in particular its emphasis on the need to strengthen the commercialization of university research, was later questioned by Dosi et al. (2006) and Bonaccorsi (2007), who provided evidence that the loss in technological strength of Europe compared to the U.S. is not due to the insufficient translation of otherwise excellent scientific research, but to the lack of excellent research as such. Indeed, the U.S. does not only excel technologically, but also scientifically. This claim was further confirmed by Lissoni et al. (2008) who showed, contrary to common belief, that European university professors are almost as active as their American counterparts in translating their research into patents, albeit through other institutional channels. Where in the U.S. many patents on findings from public research are taken by universities, in Europe these tend to be taken by firms as measured by authorship of university professors on firm patents. This is part of the evidence that Europe's relative lack of innovation compared to the U.S. may not be due to insufficient translation of scientific knowledge into innovation, but rather in producing top science in the first place.

This perspective has been echoed more recently by Mazzucato (2013) who emphasized that the innovation success of the U.S. lies much more in patient government funding for mission-oriented research, especially in the health and military domains, than in anything else. The long-term commitment of U.S. government to particular areas in science and technology, allows for risky endeavors in large research programs. She pleas for a more proactive innovation policy where government provides visions and commits long-term resources for particular technologies, for example, in stimulating nanotechnology or green energy technologies. However, it remains unclear whether policies that are effective in U.S. with a well-integrated internal market, top private universities and a large military sector, will be equally effective in European countries where such conditions are not met.

The debate about the European Paradox illustrates that the innovation system concept provides a useful policy frame to go beyond market failure reasoning alone, but also that the concept remains theoretically underdeveloped and, hence, lack explanatory power. In a fundamental sense, the theoretical weakness of the innovation system notion is inherent to its static perspective. National differences in the nature (product, process) and rate (more or less) of innovation are attributed to rather sketchy macroscopic descriptions without a theoretical model how generic institutions – here meaning the rules and laws guiding interactions between actors – would govern collaborative innovation processes. Instead, historical case studies tend to show that a major part of innovation process – especially concerning the more radical types – concerns the intentional efforts to change and adapt institutions in ways supportive of particular innovations. Put simply, institutions should be thought of not only as an independent variable, but also as dependent variable. That is, institutions "co-evolve" with technical change and market conditions (Van den Belt and Rip 1987; Nelson 1995; Murmann 2003).[1]

4. A complexity-theoretic perspective

In recent years, a third perspective on innovation policy is emerging that has its roots in evolutionary economics, and links to complexity theory in two fundamental ways. First, it advocates a different notion of knowledge than the ones underlying market-failure and system-failure approaches. Second, it conceives of a complex and country-specific space of opportunities and barriers for innovation. Combining these insights, one can argue that the additionality of any innovation policy is not just uncertain but likely to be low, with the exception of innovation policy for societal challenges.

Let us start by recalling the theories of knowledge underlying contemporary innovation policies. In the market and system failure perspectives, such a theory of knowledge remains rather implicit. In

[1] Compared to the national innovation system approach, the Varieties of Capitalism approach (Hall and Soskice 2001) is more grounded in the theoretical notions of institutional complementarities and dynamic capabilities. However, as for the national innovation system approach, this approach still has to incorporate the institutional change in the overall framework.

the neoclassical framework underlying the market-failure arguments, the notion of knowledge is primarily one of codified knowledge. Indeed, if knowledge is codified, it can easily spillover to competing firms. Writing this knowledge down into a legal document such as a patent, would then be in principle an effective instrument to protect new knowledge. The innovation-system framework underlying the system failure argument has a more subtle notion of knowledge. First, it is recognized that knowledge is distributed among many actors that all may contribute critically to innovation processes. Second, it is also recognized that a lot of knowledge relevant to innovation is tacit in nature and resides in people in the form of experience knowledge as well as organizations in the form of organizational capabilities. Hence, to combine tacit knowledge in people and organizations with other people and organizations, collaboration within and across organizations is key as well as stable institutions such as laws, norms and public policies to support such collaborations.

The evolutionary perspective, and later its complexity-theoretic elaboration, follows the innovation-system framework in its view of knowledge as distributed and consisting of tacit and codified knowledge (Nelson and Winter 1982). Where it differs from the innovation-system approach, however, is that it views innovation primarily as a process where cognitive distances between individuals are to overcome rather than institutional distances between organizations within an innovation system. Cognitive distances are most easily overcome if individuals have related knowledge base, for example, work in the same or technologically related industries as well as if individuals share the same norms and values (Nooteboom 2000; Frenken et al. 2007). By associating and recombining pieces of knowledge and technology in new ways, new products and services are being conceived that may, or may not, be successful. Collaboration central to the innovation-system perspective is one way of overcoming such cognitive distances, but this can also be done in other ways. For example, some individual firms or entrepreneurs are perfectly capable of re-combining on their own, while in other context recombination critically hinges on collaboration and collaboration within the innovation system. Furthermore, informal social networks as these exist in (on-line) communities of practices often crossing national boundaries, can be very effective in organizing innovation as well.

The central mechanism in the growth of knowledge is to recombine existing artefacts, knowledge and capabilities in new and more complicated ways (Arthur 2007). Following this, a complexity-theoretic perspective emphasizes that, first and foremost, innovation patterns are highly cumulative and path dependent. Although the notions of cumulativeness and path dependence goes back to the 1980s (Dosi 1982; David 1985), systematic evidence on how national and regional growth trajectories are constrained by the past, is only of recent date. In particular, Hidalgo et al. (2007) were able to show that countries develop their economy by diversifying into export products that are closely related to products they already export. That is, if a country currently exports mainly shoes and trousers, it is very likely to diversify into related goods (say, shirts or socks) rather than into unrelated goods (say, toys or televisions). This strongly path dependent nature of diversification in national economic development as shown by Hidalgo et al. (2007) also holds true empirically at the sub-national levels (Neffke et al. 2011; Boschma et al. 2013) and equally so for technological and scientific development as measured by patents (Kogler et al. 2013; Tavassoli and Carbonara 2014; Rigby 2015; Tanner 2015) and publications (Boschma et al. 2014; Heimeriks and Balland 2015).

If we think of products as being more or less related, and that this greatly affects the opportunities for countries to diversify and develop, the structure of the “product space” and a country’s position in it, matters. The relatedness of products in the product space can be mapped in various mays, for example, by counting how many countries are specialized in the same two products or how many people change jobs between two product industries. Whatever method is used, the resulting product space can be thought of as a network with links between related products (Hidalgo et al. 2007). Such a network is fundamentally "complex" meaning that some products are very central (that is, related to many other products) while other are more peripheral (that is, related to only few products). Furthermore, there are modules of products that are interrelated, but rather unrelated to all other products. And, relatedness can even be thought of as asymmetric: it may be easier to diversify from product A into product B, than vice versa (e.g., diversification from airplanes into cars is easier than from cars into airplanes). Given the complex nature of the product space, then, countries located in the center and have ample diversification opportunities while other may be located at the periphery or being locked in into a module.

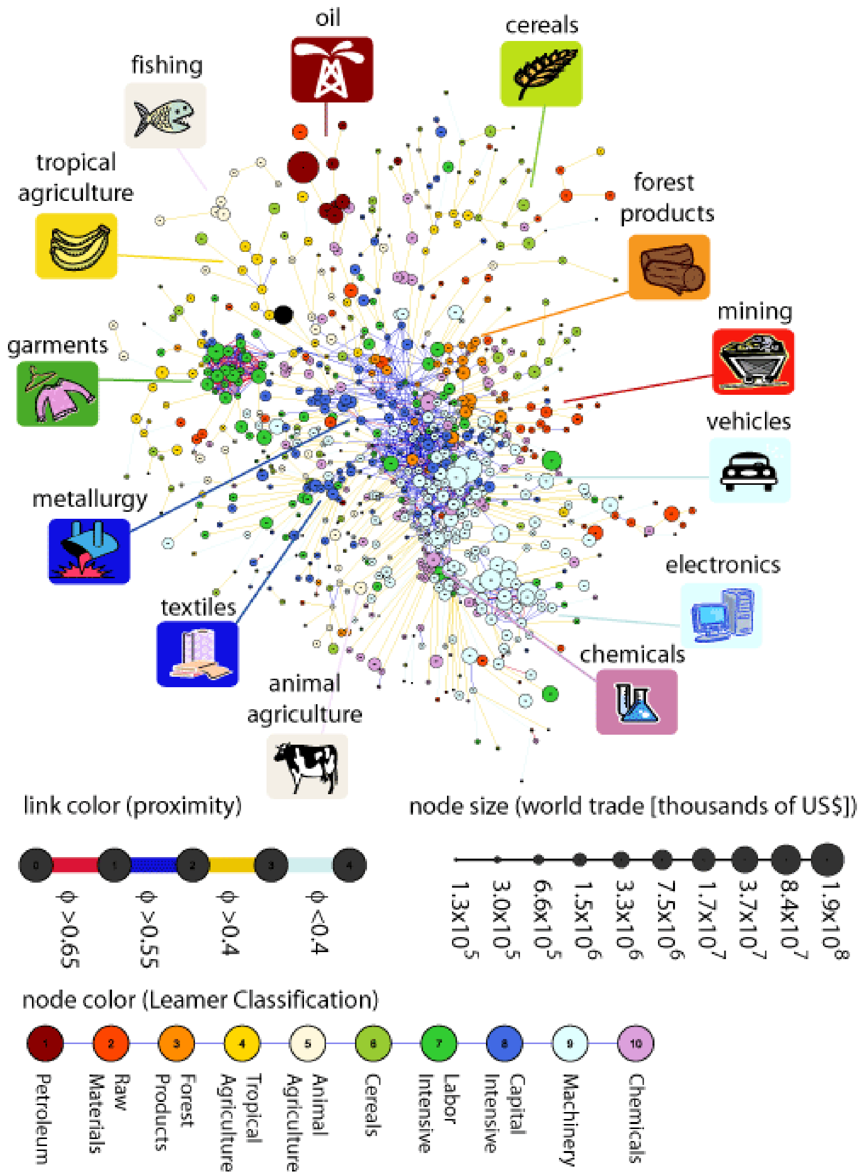

Figure 1 : An example of the product space. [Source: http://www.chidalgo.com/productspace/network.htm]

Product relatedness is strongly predictive: the chances that a country starts exporting a product closely related to existing products in a country's portfolios are much higher than the chances that a country diversifies in more distant products. The interpretation of this evolutionary patterns holds that once a country has developed the capabilities to export particular products, it can easily diversify in related products that require very similar capabilities to produce them. In basic economic terms, the reasoning here is one of economies of scope: diversification into related products allows a country to exploit the knowledge it already has, while diversification into unrelated products would necessitate a country to invest heavily as to acquire new knowledge. It is therefore not surprising that the empirical research just cited showed that most countries and regions have developed new activities closely to existing activities. This is not only a likely pattern but also a sensible pattern, as regions and countries can leverage the knowledge and competencies already present.

The innovation policy implications of a complexity-theoretic framework are not necessarily in conflict with those motivated by market failures and system failures. Indeed, a **related-diversification strategy** can be supported by generic R&D subsidies, as well as by strong collaboration within a country's innovation system. In the case of generic R&D subsidies, those trying to explore new activities are compensated for the risk they take as well as the spillovers they are likely to generate for other firms. Firms receiving such subsidies are existing firms producing products making use of an existing knowledge base, and can thus be expected to diversify in closely related products. Similarly, system failure policies will strengthen interactions between existing actors who build on existing strengths within an innovation system. Thus, a government pursuing market and system failure policies, will almost automatically promote related rather than unrelated diversification. Thus, although the outcome is predictable, generic policies do not have to pre-specify this direction and thus have the advantage that the information problem (which technology to choose) is circumvented.

There are, however, two fundamental weaknesses of market and system failures policies from a complexity perspective. First of all, though the market and system failure policies are in essence generic, large firms benefit more than small firms, as large firms do on average more R&D and have formal R&D departments to which tax benefits apply. Similarly, manufacturing will profit more than services, as the latter has little formal R&D activities and hence typically fall outside the scope of R&D subsidies. Hence, generic R&D subsidies are most likely to reinforce existing manufacturing specializations dominated by large firms. In the case of policies geared to repair system failures, again larger firms will profit most, as they are better embedded in innovation system and can bear the sunk costs involved in participating in such systems. Furthermore, with much emphasis lying on improving university-industry relations, science-based sectors (mainly high-tech manufacturing) are privileged over creative industries and service sectors, though demand as well as employment is much higher in the latter sectors than in the former. Though R&D activities coordinated within an innovation system may well lead to true new innovations, most likely these innovations will be closely related to existing strengths of incumbents in such a system, simply because innovation systems are built up by incumbent actors largely setting agenda's on their own. Put differently, a government pursuing solely market and system failure policies will generally *de facto* lead to a stimulus for large manufacturing firms to diversify into related industries. Innovation policy, thus, *de facto* is rather directed towards certain actors and sectors, rather than truly generic including startups and small firms and including creative industries and service sectors. This also explains the poor additionality of such innovation policies. Large manufacturing firms have both the resources, appropriability conditions and organizational capabilities to set-up innovation programs on their own, and with relevant partners within the innovation system. And since market- and system-failure policies will mainly lead to diversification into related products, the inherent risks associated with R&D are actually quite low, which suggests that most innovations would also been pursued in the absence of these policies.

A second fundamental weakness of market and system failures policies holds that a country that continues to develop only by diversifying into related activities runs a serious risk of running out of opportunities. It will become increasingly harder to find related activities to exploit, the more related activities have already been explored in the past (Saviotti and Frenken 2008). Hence, a related diversification strategy should go hand in hand with an **unrelated-diversification strategy** as well. In other contexts, one also speaks of the exploration *versus* exploitation and the need for "ambidexterity".

If the objective of innovation policy is to help actors diversify into unrelated activities, market and system failures arguments still remain relevant. On the one hand, the market failure argument applies *a fortiori* given that the risk involved in unrelated diversification is much higher compared to related diversification. That is, actors (firms, consumers, universities, financial institutions) will be even more reluctant to invest in unrelated activities than in related activities, which would imply that R&D subsidies have a stronger rationale in an unrelated diversification policy than in a related diversification policy. However, this risk only applies to a small subset of firms that actually pursue such a strategy, so one would have to abandon a generic R&D subsidy logic (Rodrik 2004). In practice, however, an agency granting R&D subsidies would have a hard time to assess which firms pursues an unrelated or related R&D strategy.

For unrelated diversification, the system failure argument also holds *a fortiori* because it is precisely when innovations deviate from existing knowledge, institutions and user practices, that new institutions have to be built. In a sense, one can say that a new technology-specific innovation system has to be built more or less from scratch (Hekkert et al. 2007; Bergek et al. 2008). However, an unrelated-diversification strategy calls for a different systemic policy than the one that is usually advocated. A policy is needed that aims to *change* institutions which generally requires involving new actors as well as risk-taking on the part of government itself, rather than to reinforcing existing actor positions, institutional arrangements and government roles. Such a policy is difficult, as (parts of) governments may have their own stakes in continuing existing institutional arrangements or be subject to strong lobbies by incumbent actors, and are generally reluctant to experiment with new rules and regulations. One way to allow for more experimentation then would be to decentralize innovation policy and powers to cities and regions, so that a larger variety of new techno-institutional arrangements can be built and evaluated.[2] Another one would be to create new institutional spaces by socio-technical experiments or introducing the "right to challenge" existing rules by actors who meet public interests by alternative means (European Council 2016). Yet another

[2] In this context, the rise of solar energy technology in Germany is a case in point. The national development of the industry was prompted by very localized and bottom-up processes of users and housing corporation pressuring local governments for new policies and regulation (Dewald and Truffer 2012). Only later, such initiatives were aggregated into national policies.

way is to invest much more resources into learning how to transplant successful institutional arrangements from one territory to another, or from one sector to another, or from one technology to another (Binz et al., 2014; Dawley, 2014).

Since any economy will benefit in the long run from a mix of related and unrelated diversification, the difficult challenge for governments is to come up with market and system failure policies that on the hand support existing companies and sectors in their quest for the exploitation of their existing competencies in related activities, while on the other hand support those few who wish to break with establish practices and explore more risky paths of potentially much bigger social returns. In stimulating related diversification, the state can rely on generic policies, while in stimulating unrelated diversification, the state has to focus much more on specific policies.

Though generic and specific market-failure policies may be rather easily combined – for example, by granting all firms doing R&D a (small) generic subsidy, and firms with a very risky investment specific financial support through an investment fund so that potential returns feed back into state finances – the inherent contradictions between related and unrelated diversification systemic policies are harder to solve. A well-functioning innovation system – in the sense of strong coordination and consensus on R&D activities among major actors – is probably also a system that is more reluctant to change the institutions and accept radical innovations that potentially threaten the competitive strength of incumbents. Innovation systems that are capable of providing a continuous stream of incremental innovations with firms as active agenda-setting actors and universities as responsive knowledge providers, is obviously not a system where radically new agenda's will spontaneously emerge advocating to break with past specializations and to diversify into new and unrelated territories. A further problem for any unrelated-diversification policy is how to make an informed choice and politically defend specific priorities given that so many other priorities can be chosen. By contrast, a related-diversification policy does not face these problems as opportunities emerge endogenously in a path dependent manner and political support is almost automatic given that vested interests can perfectly seize the opportunities of related diversification.

5. Societal challenges

Our previous discussion makes clear the rationale for innovation policy is greatest in contexts of unrelated diversification. At the same time, the direction of unrelated diversification is by nature undefined. The notion of cross-specialization introduced by Janssen (2015) is a first attempt to solve this apparent contradiction. He advocates an innovation policy aimed at radical innovation by promoting crossovers between unrelated technologies or industries already present in an economy (Castaldi et al. 2015). In this way, one can still build on existing artefacts, knowledge, and capabilities residing in an economy while explicitly aiming to new a very new specialization. Such true "New Combinations", if successful, may provide a long-term source of competitiveness as other countries that do not share the same specialized knowledge fields being recombined, will find it hard to copy such a success. And given that such a policy still continues to build on an economy's strongholds, but in a radically new combinations, one expect political support for such policies to exist.

A second way to guide radical innovation and unrelated diversification is to move away from existing capabilities *viz.* interest at the supply-side at the starting point, and alternatively to articulate new needs at the demand side (Boon and Edler, 2015). The current frame within which such demand-led innovation policies are being discussed, is the European-Commission frame of "societal challenges" such as climate change, air quality, sustainable food, ageing, smart mobility, Internet crime, alienation, obesity, diabetes, analphabetism, mental health, etc. There are many missing markets related to these challenges due to the fact that most societal challenges stem from negative externalities or a public-good nature of the problem. Demand articulation, then, does not only increases the chances of innovation being accepted and embraced by user publics, it also provides legitimacy and guidance for the innovation process itself.

In line with this reasoning, Weber and Rohracher (2012) mentioned legitimacy, guidance and demand articulation as key 'transformation failures', in analogy to market and system failures. In the context of the need for transformation given societal challenges, market and system failure policies lose some of their rationale. These generic policies will have little additionality in solving societal challenges for three reasons. First, it is unlikely that generic policies miraculously lead to solutions for specific societal challenges. Second, as the markets associated with societal challenges are either imperfect or completely missing, firms find it difficult and highly risky to try to serve these markets in the first place, as it is uncertain if, and if so how, future markets for such problem will be institutionalized. And, finally, the societal challenges are new, "grand" and complex. Hence, solutions will be to a large extent unrelated to technologies and institutions already existing. Given our earlier conclusion that generic policies will foster mainly related diversification, it is unlikely to trigger the more radical innovations required to solve these challenges. Calls for what Mazzucato (2013) called a more "entrepreneurial state" seem indeed justified, given both the urgency and uncertainty of societal challenges.

In the context of societal challenges, it is particularly insightful to recall an old text by Nelson (1974) who asked the simple question: "if we can land a man on the moon, why can't we solve the problems of the ghetto?" Nelson stressed that the challenge of putting a man of the moon was very different from that of solving problems in ghetto's or, for that matter, most other societal challenges including climate change, ageing, depression, malaria, floods, congestion, pollution, human trafficking, Internet fraud, and so on. The objective to land a man on the moon was well-defined and guided technological and scientific research in a clear direction. Moreover, the objective (at the time) was broadly supported by the public. Through dedicated and specific investments in Research and Development, the challenge could be met. However, ghetto-like problems are wicked and ill-defined, and how such problems should be defined is even contested (Bijker et al., 1987). Furthermore, any progress in solving such problems is hard to monitor rendering experimental intervention and *ex post* policy evaluation difficult. Finally, ghetto-problems are multi-faceted and result mainly from behavioral and social processes that are hard to understand, let alone, to influence by policy.

Given that most societal challenges are clearly ghetto-type problems, Mazzucato's (2013) call for massive public investment in particular sciences and technologies, or in public enterprises, is questionable. Only in some cases can societal challenges be easily translated in clear technological projects with the government as a strong driver. Such exceptions include for example of battery technology, drugs for rare diseases, or public infrastructures to protect citizens against flooding. However, most of the problems that can be subsumed under societal challenges will not be solved by technological fixes nor by advances in scientific research or state-led policies. Rather, a new wave of innovation policies is needed that starts from those parts of society where the challenge is actually present and partial knowledge about it is available, and then translates such a challenge into well-defined and politically supported problem (Boon et al. 2011). Only then, a "temporary innovation system" can be organized effectively, which is dedicated to solving such a problem by addressing both the economic, technological and institutional dimensions of the problem at hand.[3]

The elaboration of a societal challenge into a concrete innovation objective and policy is a key process. Without a concretization of a "ghetto-like" challenge, the problem remain elusive hereby *de facto* de-politicizing the challenge. By making a challenge operational by formulating a clear objective, the choice for supporting one or another innovation policy objective is made part of a normative process. At the same time, once such a simple objective has been formulates, (absence of) progress can easily be monitored ensuring politicians' accountability. Examples of such objectives are zero deaths in traffic, no homeless sleeping on the streets, no children with obesity, all vehicles zero-emission, etc. In this search process, finding an operational objective that finds supports from diverse political parties (often for different reasons) would nevertheless be preferable, because a challenge-led policy is often taking 5-10 years and should, hence, be able to survive changes of government. By agreeing on a concrete objective, a temporary innovation can be effectively an legitimately organized as the true relevant stakeholders can only now be identified. At the same time, the objective sets an agenda – or an "innovation trajectory" if you will – for stakeholders to jointly pursue and a yardstick allowing evaluation and learning during the innovation process, rather than *ex ante* or *ex post*. In this way, a shared and concrete objective greatly reduces the inherent cognitive complexity stemming from the ghetto-type nature of societal challenge as well as the organizational complexity stemming from the distributed nature of expertise among stakeholders.

The formulation of a clear objective mobilises existing organisations to work together in findings ways to meet it, through collaboration an coordination of actions fitting in their respective roles and competence. In this context, Kuhlmann and Rip (2014) speak of tentative governance rather than working from a master plan. That is, the objective is there, but the way(s) to achieve is an emergent outcome. A temporary innovation system thus cuts across existing, more institutionalised innovation at sectoral, technological and territorial levels. Given the a single guiding objective and its temporary nature, there is no need to institutionalise the temporary innovation system itself, avoiding possible clashes between already existing institutional logics, sunk investments and interests. Yet, if particular solutions that emerge from temporary innovation systems are successful, the solutions can effectively become adopted in existing institutional frameworks and may also be the basis as a new export product to countries dealing with similar challenges (Dewald and Fromhold-Eisebith 2015).

Finally note that temporary innovation systems can take many forms, including urban innovation programs, sectoral voluntary agreements, monitoring and labelling instruments, social enterprises, government Task Forces, citizen movements, online communities, etc. The plurality of governance structures is unavoidable and probably necessary, given the variety of technological, institutional and political contexts in which such "pop-up" innovation systems emerge. In some arrangements, governments can take the lead and be directive and financially supportive, while in other contexts the absence of government (and possibly even lack of law enforcement) is most productive.

[3] My notion of temporary innovation system fits with an earlier knowledge of Mode 2 knowledge production, contrasting the traditional Mode 1 notion of independent "ivory tower" university research with new notions of academic engagement, open innovation and temporary network organization (Gibbons et al. 1994; Hardeman et al. 2014).

6. Concluding remarks

In this essay, I have summarized market-failure and system-failure arguments that constitute the dominant frames in current innovation policy. Next, I have proposed a third complexity-theoretic perspective stressing the path dependence of economic development resulting from the tendency to diversity into related rather than unrelated activities. As a consequence, I formulated the need for unrelated diversification policies, especially in light of the grand challenges that societies are facing today. I ended by concluding that given the inherent complex, contested and behavioral nature of societal challenges, a return to technology-push strategies in the tradition of "man-on-the-moon" projects is undesirable except in rare cases. Instead, I suggested to translate challenges into concrete objectives and then to build dedicated "temporary innovation systems".

For innovation scholars, then, the research challenge regarding temporary innovation systems will be twofold. First, we will have to understand why certain governance structure emerge in certain contexts, and what renders them effective and durable in their intended outcomes. This links to the broader question of how institutions change in which is taken up *inter alia* in the institutional-sociology literature under the label of institutional entrepreneurship (Battilana et al. 2009). Second, we may have to transform current innovation systems into a "meta" innovation systems that facilitate the setting up of temporary innovation systems including ambitious societal objectives as well as effective structures to diffuse contextualized solutions across territories and sectors. This links to the broader political-science question of policy learning and institutional transplantation. For both questions, it holds that innovation studies as a field has to loosen its traditional prime focus on the economics discipline and has to open up much more to the fields of institutional sociology and political science.

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