How to Stimulate Convergence and Emergence of Technologies?

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Until the last century, technology development and application, e.g., manufacturing and commercial application, were often centered in reasonable proximity which led to the thinking that regional industry absorbs regionally developed technology at reasonable pace. While this view is certainly true, it neglects that also industry is developing routines over the years which are often hard to overcome, e.g., although technology and skills are available locally, industry might postpone modernization and skills upgrading due to delayed decision-making and limited willingness to leave the old routines as David (1990) describes for the advance of the "New Economy."

From the technology point of view, accelerated diffusion speed brings positive effects when it comes to the sophistication of technologies and the search for complementary application fields and so on. But from the point of view of regional and local development, this becomes even more questionable because the absorptive capacity of existing industries in close proximity of the technology's place of origin is not necessarily sufficient to take advantage of the next technological wave. Moreover, it appears that building new industrial zones for economic development is more comfortable for companies, namely, large companies, than upgrading existing facilities to master new technologies well. Among the reasons for preferring, establishing new facilities is the fact that technology intensive manufacturing is frequently capital intensive which for accounting and controlling reasons might tempt companies to favor new facilities over existing ones due to the depreciation of existing assets and also for reasons of public subsidies, loans, grants, or the like which is often offered to companies investing at green field. It therefore cannot be assumed any longer that the supporting technology development will provide local

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and regional spillovers for the benefit of respective economic and social value with close proximity to the place of origin. In this respect one might argue that local and regional development should change the existing paradigm of "investment into research and technology development creates lasting regional economic advantage" toward a broader understanding of the resulting spillovers. These spillovers are not necessarily bound to appear in a region but might appear elsewhere in the world which lets the question arise why investment was done in one region but the impact achieved in another region.

Accordingly governments are challenged to justify why public intervention is actually required to stimulate the emergence and convergence of technology. At first sight any government intervention seems doubtful in light of the market economy thinking which postulates that the market will balance demand and supply. The failure in this thinking however is that technologies in many cases don't generate new demand but replace existing solutions, e.g., making established technologies obsolete. Assessing the eventual impact resulting from these replacements on the respective economy appears difficult for several reasons. First of all challenges arise in assessing the actual technology-induced economic but also societal impact. Economic impact is frequently measured by job creation and economic returns of a technology but still in most cases the impact which a technology has on revenue generation remains uncertain. For example, frequently products, services, and processes involve several technologies which is why solid economic assessment is only partially possible. Similar is true for the societal impact which evolves. It's not always clear and predictable which impact a technology or bundle of technologies might have on society in advance and also the causality between the emerging technology and societal impact is difficult to assess. Having said this we find that impact assessment is still characterized by the chicken and egg problem, but for government interventions, it's almost essential to know the possible impact. Against this background numerous reasons for governmental intervention in technology emergence and convergence appear:

- Among the governments' ambitions for technology development is the explicit aim to enable companies to develop new products and improve processes at broader scale for manufacturing which eventually results in economic growth (Cooke and Leydesdorff 2006). This is an obvious intention by policy makers; however firms' competitive advantages result from their presence in the value chain (Krugman 1995; Porter 1990, 1998), e.g., especially in course of open markets and global value chains, companies tend to diversify their value generation activities. Value chain-related activities are typically spread across different locations, e.g., countries and regions. But this does not imply that each step or activity of the value chain is established in one region only. Quite on the contrary, companies, especially large companies, operate different facilities in different regions for various reasons. Among the motivations are the end consumer proximity as well as the regional supply chain for selected products and service features, the servicezation of products for which regional proximity is a plus but also the human resource dimension in all facets and in some cases national

regional regulations which requires this (Miozzo et al. 2016; Miles 2016; Miles and Miozzo 2015).

- Whereas in the early stages of the technology life cycle only few knowledgeable individuals and entities are involved and competent to apply and further develop the technology, the number of parties increases considerably with growing application diffusion. Typically, there is uncertainty about the eventual possible applications an initial invention might bring over the lifetime which is due to the small and often closed community of individuals who are engaged. Frequently these individuals are primarily scientists and dedicated engineers who aim at the perfect scientific and/or engineering solution with little or limited attention to application fields. Thus discussions about the technologies are mainly limited to community internal debates at least for a while. Following the involvement of a broader public audience, namely, a scientific and engineering audience, more views and perspectives on the technology under consideration appear which provides the ground for very early adoption (Helpman and Trajtenberg 1994). It follows that information about the existence of the invention, hence technology, diffuses and more actors are becoming aware of the potentials. Increasing awareness of the inventions outside the initial communities also brings spillover effects which cross regions and countries in addition to the initial technology field. Therefore, an invention might show potential to stimulate activities in other regions which for some reason provide better framework conditions for the invention to unfold its economic and application potential than locally only.
- Technologies typically originate at a dedicated location but show limited application potential and economic impact, respectively, in the very early stages. The challenge arising is that technologies diffuse fast within and beyond communities, and therefore locations and regions of origin might experience that the merits of applying and exploiting technologies are grasped at another destination. This observation is by no means a twenty-first century phenomenon but has been described in the 1980s already (see, e.g., Cooke et al. 1984). Creating measurable economic value from technology is hardly an issue for scientific and engineering work and related competencies only but is extended to the common business, operations, and maintenance skills which are essential for manufacturing and production hence for economic value. Economic value here involves local and regional employment creation but also tax revenues to the local and regional public budgets. In addition value to society arises through more indirect value, e.g., by means of employment which in turn contributes to social welfare and less social tensions among many others. For these reasons technology creation is often seen by the policy community as a means of long-term value creation. However, in many cases respective support measures are aimed at initial technology development in the first instance but less on timely providing adequate labor force competences, which is companies' absorptive capacities in the broadest sense. Beyond scientists, engineers, and other related highly qualified, labor industry demands lower skilled—but still flexible—manpower for manufacturing. Again this is hardly a new observation but has been described by Saxenian (1981) already. What has changed since then is the even faster

diffusion of information thus technology and obviously technology's complexity and interdisciplinary nature.

As in any technology development case, completion is always uncertain both with regard to completion in time and budgeted resources which is why it appears to be little constructive to talk about emerging technologies if there is no certainty about completion. Furthermore, users' technology acceptance might be indicated, but this again is highly risky and uncertain because competing technologies are potentially also in the development stages, and the actual technology performance remains rather vague with much of the potential value being assigned to expectations and enthusiasm. The latter is also a potential barrier for acceptance and diffusion if the technology under development eventually doesn't provide reasonable value to users to replace existing solutions or to enter new grounds base on the new technology. Therefore, the psychological dimension is crucial to consider. Against these arguments the authors understand emerging technologies as:

> Solutions of which basic principles and modes of action have been developed and demonstrated successfully. Initial applications of the technologies are known and at least partially understood but there are additional yet unexplored application fields. Emerging technologies are in principle platform technologies in their early technology life cycle stages. A technology might be entitled 'emerging' if it is in operation for demonstration purposes at least and multiple application fields are possible.

Among other features emerging technologies are characterized by their potential to initiate new discoveries and inventions which are based on their initial invention, e.g., the level and degree of their multiple usage potential (David 1990; Youtie et al. 2008). This includes that emerging technologies aren't diffusing a single application field only but provide the basis for complementary technologies which in turn form significant parts of new technological solutions in other fields. From a technological point of view, this is closely related to complementary technologies, in other words platform technologies, which share a common main principle stemming from an earlier invention.

Like any technology emerging technologies are frequently challenged by the prevailing uncertainty about potential side effects and less favorable impacts on society, namely, in the environment, health, and safety (EHS) context. Thus in order to generate economic benefits, thorough assessments of the technologies are required which are aimed at society and related impacts in the first instance. These assessments also request a dedicated media and information campaign targeted at informing society and raising awareness. Experience with various technologies provides evidence that the emergence of technologies and related economic effects might suffer from societal resistance if no early-stage awareness and information campaigns are in place. In such cases technological development progresses at high speed, but knowledge and information about the technology are trapped in a rather closed community with selected information pieces being made available to a broader audience. Consequently, media and interested communities use the available information pieces to communicate among society but run danger of drawing

misleading pictures of technological impacts which might influence societal opinion about the technology at large thus finally determine acceptance or resistance. Accordingly, investments into further technology and application development are at stake as long as investors are confronted with uncertainty about society attitude toward technologies.

Emerging technologies are characterized by numerous uncertainties including technological development (achieving reliability and operationality under time and budget constraints), competitive technologies development, market and user development, standards, state regulations and certifications, among others. All these features evolve and develop over time with different impact on the technology itself, and also they influence each other to some extent. A suitable instrument to visualize and understand these developments and effects are roadmaps, i.e., roadmaps dedicated to emerging technologies and economic development. However, such roadmaps are only impactful if building on a series of mini roadmaps under a common umbrella which enable regional actors at least to build their own targeted strategies and roadmaps (Walsh 2004).

Another important challenge for achieving economic value from technology development, namely, the diffusion of emerging technologies, lies with human resources. It's frequently argued that labor is mobile but still causing considerable cost to employers which was postulated 35 years ago by Dorfman (1983). The labor mobility-related cost has increased considerably over the last years when numerous countries, regions, and locations (municipalities) have decided to develop local hubs for technology development at the leading edge. Often these initiatives are challenged by a shortcoming in available talent with respective competences and the necessary integration into the appropriate communities and networks. Thus demand for such talent has grown, while supply remained at the similar level. Furthermore, it cannot be expected that supply of such talent increases at the same speed as demand develops.

In many cases technology is non-rival, e.g., it provides multiple application possibilities which can be developed at marginal costs (Fu et al. 2011). Even the digital (knowledge) economy technologies field remain featured by a significant share of tacit—hence non-codified—knowledge which provides advantages for regional and local innovation (technology) ecosystems as postulated by Jaffe et al. (1993). Such advantage is mainly found in a time advantage which the research (viz., research institutions and universities) and also the innovation (namely companies) communities in a region enjoy over other actors outside these regional communities. Yet these advantages are hardly of long-lasting nature since reverse engineering and international labor mobility enable competitors to copy or invent other related solutions. In this regard labor mobility is especially important as this affects the tacit knowledge which becomes accessible if skilled labor is moving to other places and occupations.

Diffusion paths of technologies, including emerging technologies, take a broad range of shapes, among which are trade of goods and capital by means of inward and outward foreign direct investment, mobility of people, cross border R&D and innovation collaboration, media and social network communication, and, last but

not least, the global value chains (Pietrobelli 1996). Global value chains and labor mobility are becoming more and more central to diffusion as these channels include the physical transfer of technology (GVC) and the tacit knowledge which is necessary to operate technologies. Information-related channels (social networks and media) more likely have an awareness and less sophisticated information function.

Regional proximity of actors is an important driver for technologies to diffuse in the application sphere. It is often found that face-to-face communication of actors is supportive for technologies to emerge and diffuse at higher speed (Ku et al. 2005). The rationale behind this observation is that face-to-face communication allows the actors involved exchanging tacit knowledge, e.g., direct verbal communication about the technology under question takes different forms than in more structured and documented communications. Closer regional proximity of communities demonstrates positive effects on the social relationships of actors which results in free discussion of ideas leading to positive externalities—i.e., information and knowledge dissemination—and building of trust among individuals. Social relationships and resulting trust development provide a clear contribution to the absorptive capacities of actors, namely, firms, which also contribute to technology diffusion and adoption speed (Fu 2008). The latter offers strong potentials for technological development and thus economic development but at the same time inherits reasonable threats for entities, namely, commercial entities when it comes to labor mobility between the actors involved (Ku et al. 2005).

In this respect emerging technologies clearly provide strong opportunities for generating economic impact at company and at regional level, e.g., at micro- and macro-level. However, in order to leverage emerging technologies' economic potential for the advantage of regional economic development, a much broader approach to science, technology, and innovation (STI) policy is required with dedicated features:

- Standard (common practice) STI policy measures targeting at supporting technology development but should provide more room for creativity in the design of projects and application fields.
- In order to establish lasting economic impact and provide the respective framework conducive to sustainable technology-based leadership, policies need to look beyond the initial technology horizon. This implies the active support of related regional innovation milieus and ecosystems by means of developing and keeping human resources which are at the front of the technological dimension but which also possess a broader experience and related soft skills.
- While there is a reasonable amount of scholarly works done on soft skills, the key messages haven't diffused to the national STI policy-making communities. Related policy measures share the common understanding so that featured ecosystems evolve in clusters and platform or by attracting talent without any additional support. But this is only a part of the truth. Clusters, platforms, and the like certainly play a role and might act as nucleus but hardly involve the potential to influence individual's attitudes which on the other hand is key.

STI policy is hence required to take these challenges into account if it aims at finding ways to enhance technology emergence and convergence. Obviously measures responding to the described challenges are hardly found in the narrow understanding of STI policy but beyond the common measures. It requires unorthodox approaches which provide reasonable space for interpretation of societal attitudes, legal issues, and other related regulations. Although this might in some cases contradict the standard rules and procedures of public spending—which is in almost all countries worldwide strongly regulated—policy should develop models which allow a more creative and pragmatic support. This involves especially:

- Supporting individuals aiming at extending and broadening their horizon in fields other than their current or previous education but always in line with the clear ambition to use the experiences gathered for the advantage of regional development. This is easily said but difficult to implement. Some might argue that such public support schemes take the form of scholarships which can hardly provide guarantees of receivers' return and impact generated. Right on the contrary, if a reasonable effect is expected, regulations should be as flexible as possible without putting much administrative burden on the receiver's side and leaving aside attempts to assess and quantify the resulting impact.
- It's appropriate to establish schemes which take the shape of "play money" being spent and invested with uncertain return.
- Further this requires that aims and goals of public support are formulated in a more flexible form as currently practiced and no definite fixed indicators and deliverables are described. In doing so governments are asked to obtain a more entrepreneurial attitude which is not expressed in standardized public announcements.
- Establish a system innovation thinking which incorporates user understanding, e.g., STI policy measures need to account for the requirements and perceptions of technology and innovation adopters from the initial support phases.

Summing up, we find that emerging technologies provide significant opportunities for companies and research institutions. However, the widespread expectation that emerging technologies deliver significant regional economic impact is often fulfilled partially only due to economic constraints and global spillovers. In order to leverage the economic impact in favor of the region of origin, policy makers need to look beyond the existing policy measures. This said means especially concerted—e.g., consistent and coherent—STI policy approaches are required. It is a common policy maker dilemma to develop new STI policy measures which aim at supporting emerging technologies, but in very few rare cases, the existing STI policy mix is rethought fully. For technology developers and applicants, however, it is much more important to experience a seamless and consistent sustainable policy mix; however, the respective actors are often critical and skeptical against considering changing framework conditions.

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