Innovation diffusion, technological convergence and productivity growth

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Technological diffusion is a crucial factor in fostering productivity growth. It is worth noting, however, that this process is not merely the replication and imitation of known and well established techniques, although this may be a substantial part of the whole, but the spreading of innovations across different firms belonging to different production sectors. Whilst the most radical form taken by this process is the diffusion of a technological paradigm, it also involves the piecemeal adaptation of new artifacts to different usages and productive purposes. In any case, it clearly hinges on knowledge and information transmission. As early as 1958, March and Simon (1958), in a seminal contribution concerning the functioning of organizations, held that much innovation results from borrowed knowledge, that is from knowledge firstly developed in other firms or in other industries. More recently, this important theme has been further investigated by the work of Cohen and Levinthal (1989, 1990). Their case is based on the well tested argument that new knowledge is strongly dependent on previously accumulated knowledge. Furthermore, these authors argue that firms that carry out and invest in R&D are capable of adapting knowledge originating in other firms. This is clearly a process that accounts for much diffusion and ultimately for technological convergence.

The purpose of this paper is to study a process of diffusion of an innovative technological principle in an economy featuring a high degree of heterogeneity both in terms of output variety and of the technologies that are accordingly employed and investigate the conditions leading to its application throughout the whole economy, namely the conditions for the emergence of technological convergence. The first issue that is addressed is the mode of transmission of relevant knowledge and the nature of firms' proximity that enables it. Although much literature has dealt with geographical networks and clustering, consider for example the rich spate of contributions on industrial districts, we take the view that in light of the new means provided by information technologies what matters most is technological rather than geographical proximity. At least for the purpose of investigating innovation diffusion, situations where the introduction of the new technological principle needs only minor innovations, that is, a mere adaptation, are distinguished from situations where major innovations are required. We envisage a clustering principle responding to a criterion of technological capability that selects firms on the grounds of the paradigm they belong to, the inherent problems they face, the corresponding skills and expertise they possess. The economy that results from this view of firm heterogeneity is an ensemble of clusters that differ in terms of their technological profile, each collecting firms that produce different things but that are technologically alike. Within each cluster, firms are still heterogeneous in terms of their performance and the goods they produce but exhibit a high degree of technological likeness. It is important to stress that the proximity of technological clusters is not defined at the beginning of the process but depends on the evolution of the technology.

We then proceed by setting at the root of the new principle diffusion an original improvement embodied into an artifact produced by an intermediate good producer. This artifact can be conceived as a specific implement, a means of production be it hardware or software or even more generally an organizational rule-book, that if successful is adopted by a firm that produces a final good. The implied user-producer linkage establishes the initial step of a diffusion process that occurs, firstly, within a cluster of firms of likewise technological features and, secondly, that may extend to technologically more distant ones. Since firms are heterogeneous, diffusion implies that the original innovation be adapted to the specific needs of a new user even in the case of technological proximity. This means that, for diffusion to occur, information must spread and, as a consequence, engender learning about different usages and applicability of the original innovating principle, about how to adapt it to different technological and production circumstances. It is a process that can be dubbed learning-to-adapt. This process is crucial for the original innovator to develop the capabilities that are required to perceive and, indeed, to discover with positive probability new technological opportunities that open the way for adoptions in firms that are situated in technologically further away environments, that is in different clusters. These technological opportunities cannot be taken as a given fact: there is no *a-priori* proximity to allow for effortless crossover. On the contrary, it may well be the case that there may be no way to technologically pass from one cluster to any other. As argued in recent literature (Silverberg and Verspagen, 2005 and 2007) we take the view that for percolation to take place a feasibility bridge must be developed, opening with a probability that discounts the possibility that none may in fact appear. Although seen *ex-post* diffusion of technologies appear as well defined trajectories, yet, for them to emerge, complex searching processes have to be set off. In this paper, it is conjectured that technological opportunities to successfully find applications in distant clusters emerge as a consequence of innovative success that is preliminarily scored within the clusters where the innovation has first been implanted. It is this kind of success that generates a technologically convergent cluster network.

The learning-to adapt process lays the ground for a success breeds success feedback but it is a necessary condition not a sufficient one. Leaping across technological barriers is an effort of a very challenging nature and quite distinct from that required to within-cluster diffusion. The innovator faces the two targets, within-cluster and cluster-to-cluster diffusion, by employing different and specific means that translate into different kinds of innovative investment, where the difference is not so much quantitative as it is qualitative. Investment to innovate is the key to diffusion and the strength that powers the percolation process. In the former of the two patterns mentioned, it drives the propensity to adopt by fixing the probability that firms actually do so as well as the learning-to-adapt effort by setting the probability to generate further technological opportunities. In the latter, it supports a possibly more complex searching process aimed at applications in different technological spaces. Yet, investment is warranted by profit expectations. The innovator invests in view of returns that are likely to be obtained and subject to expectations as to the likelihood of inside the cluster and across cluster diffusion. This fact places the innovator-producer at the centrestage of the innovation process.

Even great innovations fail. Whilst books of blueprints continuously see the light, few withstand the rigour of useful and profitable application; even technologically excellent artifacts may find it difficult to break through the wall of economic adoption. Several reasons have been indicated to shed light on these occurrences from the failure to understand the so-called technological ecosystem to the absence of a network of bonds linking producer-innovators to final users; at a more microlevel, the innovator's want of farsightedness as to the ultimate implications, applicability and relevance of a technological paradigm. The latter is, in fact, the key of our analysis and we define it as the vision, or lack thereof, of the original innovator, namely the capability to see through the immediate relevance of a new implement to project further and foresee distant but possible applications. We devise a measure of intensity of such property that if there may carry the innovation deep down the branching process of technology diffusion or, if not, may spell its early extinction.

On the strength of these considerations, the paper presents a model that construes a Galton-

Watson stochastic process and then determines: (i) the expected level of profits that the diffusion is likely to generate as a function of investment recursively applied to spread and adapt innovations within and across clusters: (ii) the expected number of innovations within each cluster upon which further, more radical innovations are likely to be achieved; (iii) the expected number of clusters that can be reached; (iii) the construction of a network that defines the extent of technological convergence. Finally, implications for productivity growth are assessed.