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Innovation diffusion, general purpose technologies and economic growth

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Introduction

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 it is characterized by a sequence of innovations through which the technology is spread across different firms belonging to different production sectors. Whilst the most radical form taken by this process is the diffusion of a general purpose technology (GPT),[1] 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, Cohen and Levinthal, 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.[2]

The purpose of this paper is to characterize the innovation activity and the growth rate of an economy featuring a high degree of heterogeneity both in terms of output variety and of the technologies that are accordingly employed and to investigate the mechanics through which a single technological principle is introduced through the whole economy, becoming thus a GPT. Output and sector diversity is a characteristic of a technologically heterogeneous economy reflecting a rich knowledge base. A dense sector structure, therefore, covering a large range of the product space is the consequence of but also a factor generating cognitive overlapping. In economies where the latter prevails a pool of common skills, know-how and technological competence emerges bridging different and otherwise distant sectors. Thus, diffusion is more easily achieved in a production context in which this structural characteristic is prevalent and, if successful, it is conducive to greater technological proximity. We hold that this factor is crucial in determining the extent to which a new design or technology spreads through the economy. We show that if the technological distance between products is sufficiently large, the economy is likely to remain trapped in a no-growth equilibrium in which innovations remain isolated events, while if sufficiently short, innovations eventually percolate throughout the whole economy, leading to technological convergence, the emergence of GPT and sustained long run growth. In other words, if the overlap in the economy's knowledge base is sufficiently large, then the economy converges towards an equilibrium where idiosyncratic ideas diffuse throughout the economy and translate into new technologies eventually becoming long-lasting innovation waves supporting economic growth; otherwise, they remain isolated with scarcely any consequence on growth.

Given the heterogeneity of technologies, a problem of firms' proximity arises. Proximity in our model is defined in terms of technological distance.[3] 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 because of the new means provided by information technologies what matters most for innovation diffusion 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. Historical evidence has in fact indicated that the effective diffusion of a new technological principle has often required enabling complementary innovations (see Bresnahan and Trajtenberg, 1995, Goldfarb, 2005). We envisage a clustering principle responding to a criterion of technological proximity shaped by the inherent problems faced by the innovators and 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 that are, nevertheless, 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.

We distinguish two types of investments. Investment aimed at the discovery of a technological principle and investment aimed at its diffusion throughout the economy. While the first is quite standard, the second one is the consequence of the assumption that firms employ heterogeneous technologies; hence, diffusion implies that the original innovation must be adapted to the specific needs of a new user, even in the case of technological proximity. We assume that investment in within-cluster diffusion gives rise to a learning-by-doing process that may lead to ideas and plans generating opportunities to introduce the said principle into firms belonging to other technological clusters.[4] In other words, it is conjectured that opportunities of successful applications in distant clusters emerge as a consequence of innovative investment. The latter is seen to lead, on the one hand, to score success within clusters and, on the other as a result of learning, to generate technological opportunities to cross over to distant ones. It is a learning-to adapt process that lays the ground for a success breeds success feedback: a necessary condition, yet not a sufficient one. Leaping across technological barriers is an effort of a very challenging nature and quite distinct from that required by within-cluster diffusion. The assumption that we make is that meeting this challenge to cross-over to distant technological environments depends on the technology intrinsic characteristics.

Our paper is related to the literature on the diffusion of GPT. Helpman and Trajtenberg (1998b) study a model where sectoral diffusion of a GPT requires the development of new components before becoming profitable. Most of this literature studies the consequences they imply, such as long-term growth accelerations and slowdowns (Helpman and Trajtenberg, 1998a), the resulting wage inequality (Aghion et al., 2002), or the reaction of the economy (Jovanovic and Rousseau, 2005). We instead focus on the mechanics through which GPTs emerge. Andergassen et al., 2006, Andergassen et al., 2009 investigate in a model of innovation diffusion and economic growth with local interaction among heterogeneous firms the conditions for the emergence of technological convergence.[5] While in these papers it is general information that is exchanged between technological neighbors, in this one we study the mechanics through which, starting from a novel technological principle, entrepreneurs' investment decisions to adapt innovations can eventually lead to their diffusion, the emergence of GPTs and to economic growth. This approach allows us to make predictions about the characteristics of technologies that are more likely to become GPTs and to device policies that foster the diffusion of innovations and thus economic growth. Our paper is grounded on the Schumpeterian growth literature (Aghion and Howitt, 1992 and see Aghion and Howitt, 2009 for a survey) which emphasizes the importance of competition for profit flows among entrepreneurs as a determinant of economic growth. In addition to the time span over which entrepreneurs earn rents for a single product (time dimension of profit flows), innovation incentives in our framework depend also on the number of adoptions in different sectors (technology space dimension). These two dimensions shape innovation investment incentives and drive the process of emergence of GPT, technological convergence as well as economic growth.

The remaining part of the paper is organized as follows. In Section 2 we discuss the innovation process. In particular, we describe technological clusters, the process of within- and between-cluster diffusion, the time and space dimension of the innovator's profit flow and determine the innovator's incentive to invest in the discovery and in the diffusion of the technological principle. In Section 3 we characterize the resulting emergent properties of the diffusion process and the features of economic growth. In Section 4 we generalize the model by considering the diffusion of heterogeneous technological principles and competition among an endogenously determined number of entrepreneurs that invest in R&D. Section 5 draws some conclusions.