Diffusion as a Process of Creative Adoption

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ABSTRACT. This paper elaborates an integrated framework for understanding diffusion as a process of creative adoptions in the business sector. Within the context of the economics of localized technological change, adoption is viewed as a complementary component of a broader process of adjusting the technology when unexpected events in the product and factor markets push firms towards a creative reaction. When the stock of adoptions exerts a suitable combined effect both on the gross profitability of adoption and on the costs of adoption, such that the net profitability of adoption and hence the rates of new adoption follow a quadratic path, the dynamics of creative adoption can engender a S-shaped diffusion process.

Key Words: localized technological change, net profitability of adoption.

JEL Classification: O3, L1

1. Introduction

The study of technological change has made many progresses by means of artificial disjunctions between aspects that it is difficult to separate. The traditional divide between innovation, adoption and diffusion can be reconciled in the context of the economics of localized technological change, focusing the analysis of the determinants of the adoption process.

The new attention to the active role of consumers and user–producer relations in understanding demand and in shaping technological change brought about by Bianchi (1998), Metcalfe (2001) and Witt (2001) contributes a new approach to the economics of diffusion. The new approach focuses the role of adoption as an active process. Adoption, like other consumption, cannot be regarded as a passive attitude. It requires, instead, the active participation of users not only in terms of the search and eventual choice among a range of existing products, but also and mainly in terms of a specific and dedicated activity of adaptation of available products, either brand new, just introduced, or existing ones, to the localized and idiosyncratic needs and constraints of users, as shaped by irreversibility, routines and switching costs.

Adoption is the result of a complex process of decision-making. Firms are induced to change their technology when product and factor markets conditions do not meet their expectations and irreversible choices make adjustments expensive. Technological change consists both of the introduction of original 'never-seen' before technologies and the adoption of technologies that had been already put in place elsewhere. Even adoption in fact requires that a number of highly specific and idiosyncratic problems of adaptation and integration be solved. Moreover adoption requires that a number of preliminary activities are carried out such as the search, the selection, the identification, the adaptation and the integration into the production process and the firm at large. Technological change, for each firm, is the result of both research and adaptation activities. Both command resources and engender specific revenues. Localized technological change consists of creative adoption where external knowledge and embodied technologies are implemented with internal competence and idiosyncratic knowledge acquired by means of learning processes. The identification of the net profitability of adoption as defined by the gross profitability of adoption minus adoption costs contributes the economics of technological change. The analysis of the evolution of the net profitability of adoption in the context of the economics of localized technological change shows that the dynamics of creative adoption is able to generate a S-shaped diffusion path at the aggregate level.

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The rest of the paper articulates this approach as follows. Section 2 recalls the basic acquisitions of the economics of diffusion and adoption and elaborates the notions of induced adoption, adoption costs and net profitability of adoption. Section 3 presents the model of localized technological change consisting of both the induced introduction of new technologies and the induced adoption of technologies already available in the market place. Section 4 shows that proper modeling of the dynamics of adoption costs and gross profitability of adoption can lead to the standard S-shaped diffusion processes. The conclusions summarize the results of the work.

2. Adoption and diffusion in the business sector

The distinction between innovation and imitation has been first introduced by Joseph Schumpeter and eventually has become a landmark in the economics of innovation and new technology. A new technology, either a new product or a new process is first introduced by an innovator and eventually imitated by competitors. Imitators copy the innovation and in so doing enter the market and reduce the excess profits of the innovator. Imitation feeds diffusion and restores perfect competition.

The adoption process, that is the mechanism and the duration of the time spell by means of which innovations are being introduced and used by all perspective users, has been studied in great detail and the notion of diffusion has been eventually introduced. The economics of diffusion addresses relevant questions about the characteristics and the determinants, and the effects of the adoption process. The most controversial issue is why adoption is not instantaneous and all firms do not adopt at the same time the innovation (Stoneman, 1976, 1983, 1987).

The analysis here concentrates on adoption and diffusion of new technologies in the business sector, referring not at all to the adoption of new products by households, since the decision problem in the case of households much differs from that of firms. When households are considered the innovation under scrutiny can only be a new product. When firms are the potential adopters and imitators, the innovation can concern the full Schumpeterian range of innovations.

Adoption consists in the purchase of a new capital good, a new intermediary input or a new organizational procedure that has been supplied by upstream producers. Imitation consists of the replication of a new conduct, a product, a process, a market or an organizational procedure, first implemented by another firm. The adoption of a new capital good can be the result of the imitation of a process innovation. Imitation, defined as a form of herd behavior, however is only one of the many possible causes for delayed adoption. Much work has been going on to identify possible factors for delayed adoption either on the demand or the supply side. Other relevant factors include: (a) the reduction of information costs; (b) network externalities; (c) irreversibilities and sunk costs; (d) changes in factor markets; (e) the decrease of extra-profits and hence market prices; (f) the reduction in production costs associated to learning processes or increasing returns and hence the reduction in the market prices; and (g) the introduction of incremental innovations that implement the original innovation so as to better satisfy the needs of additional groups of adopters.

Let us analyze in more details these approaches with a closer attention upon the analysis of the dynamics mechanisms at work and the underlying assumptions. When the drivers of the dynamics are found on the demand side, diffusion, here, is defined as the process of delayed adoptions and imitations of a given innovation, with fixed economic characteristics, including the performances and the price, which takes place because of dynamics on the demand side in a population of heterogeneous agents.

The well-known epidemic contagion has provided the first and most famous frame to understand the process: in a population of heterogeneous agents, characterized by information asymmetries and bounded rationality, adoption is driven by the dissemination of information about the effective profitability of adoption carried out by all those who have already adopted (Griliches, 1957).

As soon as the information about the advantages provided by the innovation becomes available to the potential adopter, the adoption will take place. Diffusion, defined as a sequence of adoption lags, is fully explained by the characteristics of the spreading of the information. For the same token, technological resilience, i.e. the non-adoption, is simply the result of the lack of information (Mansfield, 1968).

Technological resilience can be considered also the result of inappropriate levels of the profitability of adoption of a given technological innovation. The change of relevant conditions for the population of potential adopters however engenders an increase in the actual profitability of adoption and hence leads to the eventual diffusion. A first mechanism to explain diffusion in this approach, where the dynamics takes place on the demand side, but it is not reduced to the epidemic spreading of information, is provided by network externalities.

The working of network externalities has a direct bearing on the profitability of adoption of a given innovation, when the number of its users has a direct bearing on its utility or efficiency (Katz and Shapiro, 1986). Actually network externalities, that are the effects of the stock of users upon the profitability of adoption, can be both positive and negative because of the effects of congestion. The effects of network externalities have been mainly appreciated with respect to final goods. As a matter of fact, however, network externalities can have a powerful effect both for final goods and for intermediary and capital goods. The profitability of adoption of computers in the business sector, for instance, is greatly enhanced by the number of other computers in the network and the number of other firms that can receive, send and share information protocols, files and electronic communication at large (Antonelli, 1999). In turn network externalities can be both direct when there is a direct effect of the number of adopters of a technology on its own profitability of adoption, or indirect, when the number of adopters of another, yet related and complementary technology, has an effect on the profitability of adoption of the first technology (Smith, 2004). The understanding of the role of network externalities to grasp the dynamics of the adoption process in the business sector seems especially useful at a time when recent advances in the understanding of the exponential growth of Internet networks stress the role of key-users or hubs as providers of positive incentives to enter the network. This approach makes it possible to appreciate the relevance of complex system dynamics to understand the outcome of interactions where agents are heterogeneous also in terms of their size and related extent of spillover of network externalities (Barabasi, 2002; Pastor-Satorras and Vespignani, 2004).

An important engine of adoption can be provided by changes in the factor markets when technological change is biased and there is rivalry between old and new technologies. Here diffusion can be regarded as the outcome of the increase in the profitability of adoption engendered by changes in the factor markets of potential adopters. The profitability of adoption of a superior but biased technology is affected by the relationship between the factor bias and relative factor costs. All changes in factor markets, such as an increase in relative wages, have a direct, positive effect on the profitability of adoption of a more capital-intensive technology. When the new technology is both superior and biased, two equivalent isoquants, extracted from the two maps, overlap. In such circumstances three relevant events can take place: (a) there is a ratio of capital costs to wages for which the two technologies are equivalent; (b) small changes in the slope of the isocost can engender a radical shift with the sudden adoption of the new capital intensive technology; and hence (c) a sharp discontinuity in the levels and rates of increase of total factor productivity levels of adopters. If and when wages paid by firms are not identical, but distributed with a normal density function and there is a historic trend of smooth rates of increase in wages, adoptions are likely to be distributed along a dynamic path characterized by three well-distinct regions: the first with low level but with a fast rate of increase, followed by a second where the adoption of average-wage firms take place with a sharp discontinuity and finally a region with high level of adoptions but low rates of increase. An S-shaped process can easily approximate such a process. The variance the distribution of wages is determined by the combination of local differences in the bargaining power of trade unions and specialized workers and Marshallian heterogeneity among firms in terms of market power, profitability and age, an interesting dynamic process can take place. Let us assume that profit-making firms can pay higher wages, above average levels, loss-making firms instead pay wages that are below the average and the large majority of firms with normal profits pay average wages. In these circumstances profit-making firms are pushed to adopt earlier than loss making firms new capital intensive and superior technologies and hence to take advantage faster of higher levels of total factor productivity levels with a sharp increase in its rates of growth. Such a discontinuity in productivity levels increases profitability and hence the likelihood of additional adoptions of new technological innovations. The initial conditions of heterogeneity are reinforced and the variance in the population of firms is increased with a self-reinforcing mechanism (Antonelli, 2003).

The irreversibility of capital goods and the historic duration of their economic life provide a third important dynamic factor. The age structure of the stock of capital goods of each potential adopter plays an important role in assessing the adoption rates. The sunk costs of past vintages of capital goods delay the adoption of new technologies until the variable costs of the production process with the old technology are lower than the total average costs obtained with the new technology. In this context however the rates of investment and more generally the rates of growth of each company have a strong positive effect on the rates of adoption. The expansion of the productive capacity makes it possible to adopt directly the new technology, while the effects of sunk costs delay substitution. In these circumstances an interesting dynamic process can take place: fast growing companies, in a dynamic macroeconomic context, have more chances to adopt timely the new technologies and because of their timely adoption, and hence more efficient production processes, have more chances to grow faster. The interaction between growth, investment and adoption is likely to engender a strong reinforcing mechanism (Antonelli *et al*., 1992; Antonelli, 1993).

In the supply side approach, heterogeneity of potential adopters consists in their cost conditions (David, 1969; Metcalfe, 1981). Diffusion, is now defined by the structure and the sequence of delays in the adoptions of a family of closely related technologies with changing economic and technical characteristics, rather a single and given technology with static features. Potential adopters can be ranked in terms of cost characteristics. Diffusion here is driven by the dynamics on the supply side and specifically by the introduction of an array of events including: (a) incremental changes in the prototype introduced by the innovator and or by imitators; (b) the decline of the market price due to: (b1) the entry of new competitors and the decline of market power and hence mark-up for early innovators and (b2) the positive effects of increasing returns either associated to sheer economies of scale and density, or to the dynamics of learning by doing. The sequence between the introduction of product innovations and the eventual introduction of process innovation to manufacture the new products, articulated by Utterback (1994) has also a direct effect on the decline of the market price for the new products and hence on the increase of their profitability of adoption. Both the decline of the market price and the introduction of incremental innovations can be seen as the effect of the entry of creative imitators in upstream markets (Stoneman, 1995, 2002).

In a complementary approach the reduction in the price of the new products and the increase in the scope of adoption is the result of the selection mechanism at work on the supply side. After the introduction of an array of competing product innovations targeting the same product market, a dominant design progressively emerges with relevant cost advantages in terms of standardization, specialization and division of labor, economies of scale, economies of learning and density. Once again diffusion is driven by the dynamics of the supply side (Utterback, 1994).

In a similar vein the analysis of the flows of generation technologies shows that often a certain vintage of a technology is superposed by a follow up technology, for example, Internet-based E-commerce following EDI-based E-commerce, or Flexible Manufacturing Systems (FMS) following Flexible Manufacturing Cells (FMC). If the different vintages are conceptualized as 'one technology', the adoption process can be considered as the result of the entry, on the demand side, of new niches of potential customers, attracted by the increasing scope of application of the growing variety of specific applications and customized incremental innovations.

Many efforts have been made to combine the supply and the demand side approaches into a single more comprehensive model. Much progress has been made possible by the insight of Metcalfe (1981) where the epidemic, demand side mechanism is implemented by the shifting conditions on the supply side so as to define the traditional S-shaped process as the envelope of a double shift. More recently Karshenas and Stoneman (1992, 1995) have elaborated a flexible model able to encompass the broad range of possible dynamics that integrates in an equilibrium approach both the effects on the demand and the supply side.

In this context the notion of increasing returns to adoption emerges as a key synthetic contribution. Increasing returns to adoption are found both on the demand side in terms of processes of learning by using the new technology and network externalities, and on the supply side, in terms of processes of learning by doing and economies of scale in the production of the new technology. The negative elasticity of market price to the stock of adoptions, because of the effects of competitive entry and reduction of extra-profits in upstream markets contributes increasing returns to adoption for users. When increasing returns to adoption, on both the demand and the supply side matter, small events, such occasional adoptions or changes in the sequences, introduction of new standards, especially if they take place at the onset of the process, may have long lasting, path-dependent effects on the eventual diffusion and especially on the outcome of the selection, in the market place, among competing and rival technologies (David, 1985, 1987, 1988, 1990).

When diffusion concerns the adoption of an innovation in the business sector, hence by firms rather than by households, the role of adoption costs needs to be considered carefully. The identification of the role of adoption costs paves the way to the distinction between gross profitability of adoption and net profitability of adoption. The broad range of resource-intensive activities that are necessary to identify an innovation and adapt it to the existing production process defines adoption costs. Adoption costs include the costs of search and adaptive research, the costs of scrapping the existing fixed production factors, the restructuring of the production and marketing organizations, the re-skilling of personnel, the actual purchase of the capital good and intermediary input embodying the new knowledge, the purchase of patents and licenses, the costs of technical assistance. Net profitability of adoption is the result of the algebraic sum of the gross profitability engendered by the adoption of an innovation and the costs that it is necessary to carry out in order to identify, select and finally adapt the new technology to the existing production conditions.

A closer look to the process by means of which adoption is made seems necessary. First and most important is the notion of induced adoption needs to be considered. The literature on diffusion assumes that firms are always and immediately ready to adopt an innovation as soon as they perceive it as profitable. No room is made for the search of information and more generally for the context into which decision making takes place. In our approach adoption is very much induced by a general context where firms consider that a change is necessary in order to meet their expectations and reduce the gap between facts and plans (Antonelli, 1990; Metcalfe, 2005).

The adoption of a capital good or an intermediary input is not free, especially for firms. The adoption of a new technology is in fact necessarily the end result of a broader process that includes a preliminary search activity, a comparative assessment, the substitution of existing items, be other capital goods in place, workers, suppliers, customers and other components of the current structure of the firm. Adoption can take place only when some changes and adjustments have been made to the original setting. Such changes affect both the good incorporating the innovation and the layout of the firm as it were before the introduction of the new technology could take place. Adoption can take place only when the profitability of the new layout is confronted with the previous and yields a positive result. This comparative assessment includes the costs of the anticipated scrapping of the existing capital goods and the effects of all the related changes in the investment conduct (Antonelli, 1993).

In the context of an induced adoption approach, the dynamics of adoption costs, together with the changing levels of gross profitability of adoption, engendered by the introduction of changes in upstream activities, has a direct effect on the net profitability of adoption. Net profitability of adoption is the true driver of the diffusion of innovation. The analysis of adoption costs provides fruitful insight about the understanding of both the actual determinants of adoption and the analysis of diffusion processes (Canepa and Stoneman, 2004).

Recent empirical evidence shows that the adoption of an innovation requires the active participation of the firm and as such it is the result of an activity. The characteristics of adoption activity in turn are much closer to the traditional views about original research and development activities, than it is currently assumed (Antonelli, 1991; Stoneman and Toivanen, 1997; Arvanitis and Hollenstein, 2001). Consistently much empirical evidence confirms that firms engaged in research and development activities are more prone to adopt new technologies, and this seems more relevant when the technologies under scrutiny imply adjustments in firms' production process, (Faria *et al.*, 2002, 2003).

The adoption of a new technology is in fact part of a broader process of technological change. Firms are reluctant to change their technology and are induced to introduce new technologies only when a clear inducement mechanism is put in place. As soon as the routines in place and hence the technology currently in use are being questioned, and the inducement mechanism has been initiated by some mismatch between plans and facts, the choice between the introduction of original technologies invented-here, and the adoption of not-invented-here technologies can take place.[1]

The introduction of all kinds of technological changes by a firm in fact is the result of a range of complementary activities that can be substituted only to a limited extent. At one extreme of the spectrum, technological change is the result almost exclusively of the generation of original knowledge and the novel introduction of a production factor never seen before, as such. At the other extreme of the range, there is the traditional passive and imitative adoption where the firm limits itself to purchase a good incorporating an innovation. The wide gulf of intermediary positions deserves much a closer attention. This is the region where creative adoption takes place (Teece, 2005).

The economics of localized technological change provides an appropriate analytical context to understand the mechanisms at work in the case of creative adoption.

3. The analysis and the model

The economics of localized technological change

In the localized technological change tradition of analysis firms can face unexpected changes in their product and factor markets either changing their technologies or their techniques. When the actual conditions of the product and factor markets do not match expectations, firms can consider adjusting passively to the new market conditions. Alternatively, they can consider the opportunity for the introduction of new technologies (Atkinson and Stiglitz, 1969; David, 1975; Antonelli, 1995).

The changes in techniques imply that the firm is able to move on a given map of isoquants. Because of the effects of irreversibilities and limited knowledge however technical changes engender some switching costs and some costs in terms of missing opportunities for learning. The introduction of new technologies is a viable alternative when switching costs are high and technological opportunities are good. The introduction of new technologies however is not free: it requires dedicated resources and specific activities must be carried on.

A trade-off between technical change and technological change emerges whether to change just the technique, in the existing map of isoquants or changing the technology and hence the shape of the isoquants. The trade-off will be tilted towards the introduction of technological changes when the access to knowledge is easy and conversely switching costs.

Because learning is the main source of new knowledge and learning is mainly local, and because of the irreversibility of production factors and lay-out, technological change is localized: i.e. induced by changes in factor and product markets that cannot be accommodated by technical changes in a given map of isoquants and the related price and quantity adjustments and based upon the local opportunities for learning and generating new knowledge (Antonelli, 1999, 2001).

In Figure 1 we see that a change in relative factor price affects the viability of previous equilibrium E_1. The firm can either change the technique and move to E_2 or change the technology by means of the introduction of technological innovations, so as to find a new equilibrium in the proximity of the isocline O E_1, in E_3 or (possibly) beyond. The outcome will depend upon the levels of switching costs, that is the amount of resources that are necessary to perform all the activities to move from E_1 to E_2, compared to the amount of resources that are necessary to innovate and move towards and beyond E_3.[2]

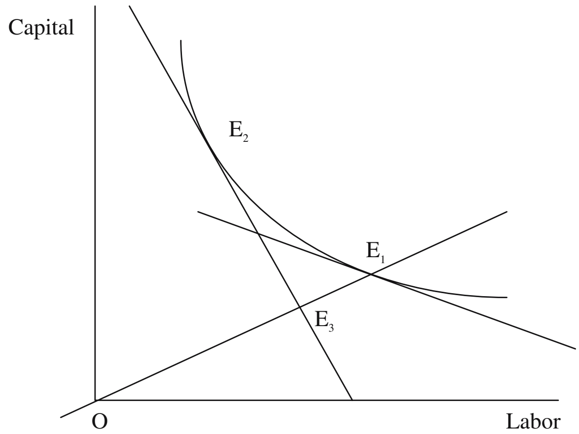

Figure 1. The trade-off between technical change and technological change.

The resilience in the old equilibrium point E_1 is out of question: the firm produces at costs that are well above the levels of the firms, typically new firms with lower levels of irreversible factors, that are able to produce in the new equilibrium point E_2.

The firm is now exposed to a clear decline in the levels of performance*s* and of satisfaction. A reaction is necessary: it can be a passive one and consist in the traditional technical change defined as a movement in the space of existing isoquants or a more creative one so as to include a change in the routines and the eventual introduction of innovations. Such a change in the space of technology can be the result of either the introduction of brand new technologies just-invented and never seen elsewhere or adopting technologies that have been already experienced by other competitors or supplied by vendors of capital goods and other intermediary inputs. The combination of adoption and their implementation with the knowledge and competence generated internally by means of learning processes that is the creative adoption is likely to be the most common strategy in these circumstances (Metcalfe, 2005; Teece, 2005).

The difference between current profits, after the changes in the market place, and the profits that should have been possible without such changes is indicative of the amount of resource the firm is ready to commit in order to bring about the changes that are likely to restore the expected levels of profitability.

In other words, because of the mismatch between expectations and the actual conditions in the markets place, the firm cannot rest in the position that had been planned. The introduction of technological innovations is a viable alternative to technical change. Both adjustments are possible but are costly. Technical change in fact, because of irreversibility of existing production factors and limited knowledge about the existing techniques, requires some switching activity. Technological change on the other hand, by definition, is not on the shelf and its introduction in turn requires some innovation activities.

Much work has been done in the localized technological change approach, to inquire into the conditions, characteristics, and determinants of the trade-off between technical change and technological change. The introduction of technological changes is possible only if appropriate amounts of knowledge and competence have been accumulated and are available to firms.

The conditions of the learning processes and the determinants of the eventual production of knowledge such as the characteristics of the internal organization and structure of firms, the structure of the local systems of innovations, the channels of communications among firms and between them and scientific institutions, the forms of interactions and cooperation between firms active in the same industry as well as across industries and diverse markets, the working of labor markets as vehicles for the transmission of information and knowledge, the management and the structure of the relations among users and producers, the positive and negative effects of the spillover of proprietary knowledge among rivals and more generally the governance of the appropriability conditions and the structure of intellectual property rights have received much attention. Much work has been also devoted to analyze the effects of the irreversibility and duration in historic time of capital goods and intangible assets in shaping the conduct of firms (Antonelli, 2001, 2003).

The role of external knowledge and supply of new technologies

Along this line of enquiry an important progress can be made when localized technological change is seen as the result of a creative adoption, that is the combination of internal competence and knowledge with the external knowledge embodied in capital goods and intermediary inputs provided by upstream suppliers or available in the form of technological information, licenses and patents.

The introduction of a new technology is induced by the mismatch between expectations and actual market conditions, and the irreversibility of production choices that have been made. The firm initiates a combined process of search and research. All opportunities to change the existing map of isoquants are now considered. The introduction of a brand new technology requires research efforts. The adoption of a new technology into the production process of a firm requires that some efforts to adapt it to the local conditions be made. The combination of the two activities yields the creative adoption of an existing technology to which a number of changes are being made so as to make it more consistent with the specific requirements of the existing production process and hence to reduce the amount of switching costs.

The choice set is now framed. The firm faces two nested frontiers of possible changes in order to solve the mismatch between plans and real markets conditions. The first frontier of possible changes is the frontier of possible adjustments, which makes it possible to compare the results of resources invested in either technical changes or technological ones. The second frontier, the frontier creative adoptions, compares the kinds of technological change. It defines a range of possible technological changes all stemming from creative adoptions. The range is comprised between the two extremes of a brand new technology, fully original, and the 'passive' adoption of an external technology.

The frontiers, the frontier of possible changes and the frontier of creative adoptions, have the usual concave shape that reflects the effects of diminishing returns in either activity. The shape is defined by the relative efficiency of the activities being considered (see Figure 2).

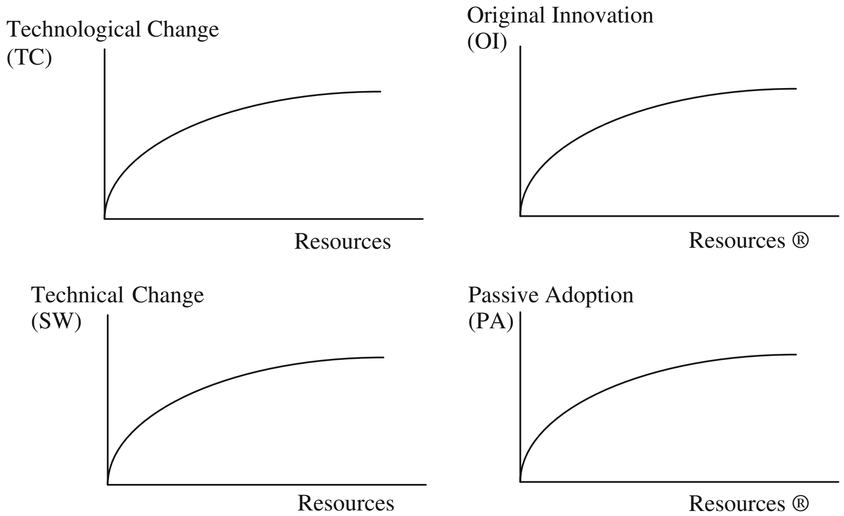

Figure 2. The production of technological change (TC), original innovation (OI), passive adoption (PA) and technical change (SW) with a given amount of resources (R).

The position of the frontier of possible adjustments is defined by the amount of resources R that the firm should invest just to switch from the previous equilibrium technique to the new one. The search for the correct solution in other words is identified as a maximization process where the firm tries and maximizes the amount of changes, including technological innovations, that can be generated with a given amount of resources set by the levels of switching costs.[3]

The firm can identify the correct solution by means of the standard maximization of the output, for two given nested frontiers, when two nested isorevenues are defined. The first isorevenue is defined by the absolute levels of the revenue generated by all adjustment activities consisting in the revenue made possible by the introduction of new techniques and the revenue made possible by the introduction of the new technologies, respectively. The second isorevenue measures the bundle of revenues generated by more-or-less creative adoption of existing technologies, that is either the original-innovation or the passive adoption.

Formally we see the following relations:

$$\mathrm{TC} = a(R) \quad (1)$$

$$\mathrm{SW} = b(R) \quad (2)$$

$$\mathrm{OI} = c(R) \quad (3)$$

$$\mathrm{PA} = d(R) \quad (4)$$

where TC measures the amount of technological innovation, necessary to change the technical space that the firm can generate taking into account the internal competence and knowledge accumulated and the external knowledge it can access; SW measures the amount of technical change necessary to move in the existing technical space and reflects the levels of irreversibility and rigidity of tangible and intangible capital; OI measures the amount of original innovation and PA measures the amount of passive adoption that can be generated with a given amount of dedicated resources (R) defined by the amount of switching activities the firm needs to complete to move from one equilibrium point to the other.

It is clear that the relationship between the four production activities is essential to define the outcome of the search process initiated by the changes in the product and factor markets. It seems clear that the larger is the efficiency in the production of technological changes and the lower the efficiency of switching, and the larger the amount of innovations introduced. Correspondingly, the smaller is the efficiency of internal research activities and hence the smaller the amount of original innovations and the smaller the efficiency of the adaptation activities and the smaller will be the amount of innovations each firm will generate. The firm will adjust to the new factor and product market conditions more by means of switching activities than by means of creative adoptions.

The extent to which the firm will rely on levels of creative adoption closer to passive adoption or will try and introduce original innovation, still based upon some levels of technological blending and recombination, clearly will be influenced by the relative efficiency of either activities and by the shape of the relevant isorevenue.

To make this point more compact, let us now assume that a frontier of possible adjustments can be considered, such that for a given amount of resources (R) necessary to face the mismatch, firms can generate an amount of either technological change (TC) or technical one (SW). Nested to the frontier of possible adjustments we find a frontier of creative adoptions that can be obtained with the introduction of either original innovations (OI) or passive adoption (PA) (Figure 3). Specifically the shape and the slope of the frontier of creative adoptions reflects the effects of the technological opportunities based upon the localized competence built by means of internal learning by doing and the opportunities offered by the knowledge and the technologies generated by thirds parties that become available either by means of imitation or by the active push of upstream suppliers. Formally this amounts to saying that:

$$\mathrm{SW} = e(\mathrm{TC}) \quad (5)$$

$$\mathrm{OI} = f(\mathrm{PA}) \quad (6)$$

In order for standard optimization procedures to be operationalized, two isorevenue functions need to be set. The first defined as the revenue of adjustments (RA) compares the revenue that adjustments by switching in the technical space (SW) yield with respect to the revenue of technological change (RTC). The second isorevenue includes the revenue generated by the introduction

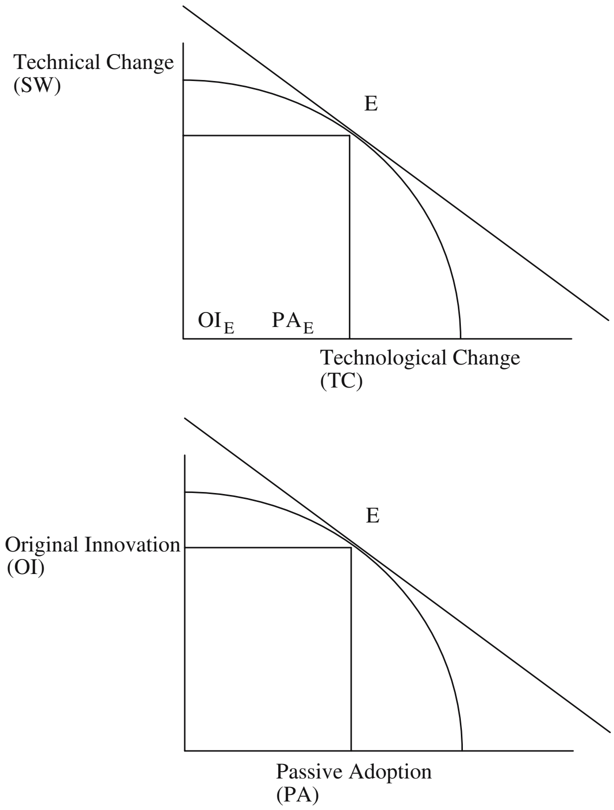

Figure 3. The nested frontiers of possible adjustments and creative adoptions.

of original innovations (OI) and the revenues generated by the passive adoption of innovations and knowledge generated elsewhere (PA). Formally we see:

$$\mathrm{RA} = s\mathrm{SW} + t\mathrm{TC} \tag{7}$$

$$\mathrm{RTC} = r\mathrm{OI} + z\mathrm{PA} \tag{8}$$

where s and t measure the unit revenue of switching and the unit revenue of technological change; r and z measure respectively the unit revenue of the amount of original innovations and passive adoption of external technologies and knowledge respectively, generated with the given amount of resources available to face unexpected changes in product and factor markets and the equilibrium amount of resources that can be identified to fund the introduction of technological change.

It seems clear that the slope of the isorevenue of creative adoptions exhibits the larger unit revenue stemming from the introduction of original innovations. They make in fact possible to the firm to command monopolistic market power and hence extra-profits. For the same token however it should be also clear that the shape of the frontier of creative adoption should reflect the larger output—for per given levels of inputs—in terms of adoptions with respect to the output in terms of introduction of original innovations: passive adoption is easier than the introduction of original innovations.

The system of equations can be solved with the standard tangency solutions so as to define both the mixes of creative adoptions, which in each specific context firms are advised to select and the amount of technological change with respect to switching the context suggests selecting. The system of equilibrium conditions is in fact:

$$\begin{aligned} &e'(\mathrm{TC}) = t/s \\ &f'(\mathrm{PA}) = z/r \\ &\text{subject to } R = R_F^4 \end{aligned} \tag{9}$$

The cases of either only technical change or only technological change and in turn either fully original innovations and fully passive adoptions are extreme solutions. Much of the real world can be found in between such extremes. Firms are induced to innovate by the mismatch between actual and expected conditions of their production set and their market conditions, necessarily built upon irreversible decisions taken on the basis of myopic expectations which are not met by the disequilibrium conditions in product and factor markets. The type of technological change is influenced by the relative net profitability of introduction of original innovations with respect to passive adoption of external technologies.

The slope of the innovation isorevenue reflects the relative gross profitability of introduction of invented-here technologies with respect to the gross profitability of adoption of technological innovations introduced elsewhere. According to the shape of the innovation isorevenue, both the composition of technological change, whether it consists mainly of innovations or adoptions, and the mix of possible changes, whether they consist mainly of switching activities or technological changes, are affected.

The equilibrium conditions identified by Equation (9) capture the essence of the dynamics of localized technological changes consisting of creative adoptions engendered by the mismatch between plans and actual factor and market conditions for firms that are constrained by the irreversibility of their choices.

4. Creative adoption and the diffusion of innovations

The dynamics of creative adoptions is able to accommodate the traditional S-shaped aggregate diffusion process provided that a set of conditions applies. It is sufficient to assume in fact that at each point in time the stock of adoptions exerts two well-distinct externalities.

The stock of creative adoptions is likely to exert a negative effect on the gross profitability of adoption. The relationship is shaped by diminishing returns: the gross profitability of adoption, as determined by the market price for the products of the firm, is higher with low levels of adoptions and declines with the increase in the stock of adopters impinging upon the basic technology until it reaches a minimum level. The rationale for this effect is easily found in the typical Schumpeterian competition as a dynamic process. Early adopters can command extra-profits associated with the creative implementation of the new technology. Eventually however, as the number of adopters increase, and the rivalry among users of the new basic technology becomes stronger, the market prices for the products manufactured with the new technology are driven to their minimum level and the conditions for perfect competition are finally restored. The understanding of this dynamics is the direct result of the new approach to adoption as the result of a creative and innovative process. There is in fact a continuum of conditions between the first producer of a new good and its first adopter which cannot be cut: early adopters are able to command transient extra-profits like early innovators. Like early innovators, early adopters experience the decline in extra-profits associated with the increase in the stock of adopters.

This is not, however, the single effect of the stock of adoptions. The stock of adoptions, in fact, is likely to exert also a negative effect in terms of a decrease in unit adoption costs. Here an array of positive effects is at work including learning processes and increasing returns to scale. Moreover, in upstream markets the entry of new competitors is likely to reduce the market prices for the basic technology to be adopted and creatively implemented with the internal and local competence of each firm. The market prices for the basic technology and the capital goods that embody the new knowledge decline as the number of adoptions increase.

It is sufficient that the combined outcome of the two external effects respect a number of simple conditions for the net profitability of adoption to follow a well-defined path that is able to generate an S-shaped process.

Specifically, as the Figure 4 shows, the difference between the negative effect of the number of adopters (N) on adoption costs on the one hand and their negative effects on the gross profitability of adoption on the other, can be isolated and directly confronted. The difference in their slopes and specifically the ratio of the values of their first and second derivatives is crucial. It is sufficient

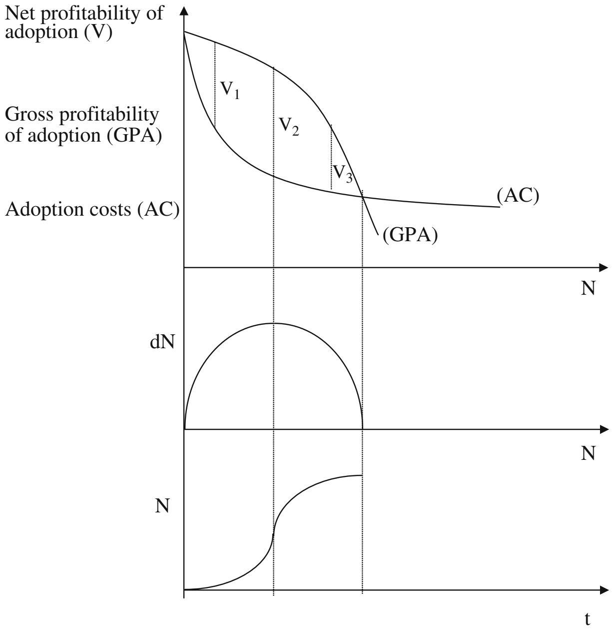

Figure 4. The dynamics of gross profitability of adoption, adoption costs and net profitability of adoption and the S-shaped diffusion process.

that the difference between the two slopes presents a combination of values that engenders a quadratic relationship of the net profitability of adoption with respect to the stock of creative adoptions, such that $V_1 < V_2 > V_3$, to obtain a typical S-shaped diffusion process. Let us put it formally:

$$\text{GPA} = m(N), \quad \text{with } m'(N) < 0, \ m''(N) > 0 \tag{10}$$

$$\text{AC} = n(N), \qquad \text{with } n'(N) > 0, \quad n''(N) < 0 \tag{11}$$

$$V(N) = m(N) - n(N) \qquad \text{s.t. } m'' > n'' \tag{12}$$

Let us recall that at as long as net profitability of adoption is found, the number of new adopting firms increases. Hence:

$$dN(t)/dt = W(V(N)) \tag{13}$$

Given the properties of W and $V(N)$ it follows that:

$$N(t) = \int_t (dN(t)/dt)dt = \int_t W(V(N))dt \tag{14}$$

Equation (14) establishes a functional relationship between the flow of adopting firms and the stock of adopters.

The $p(N)$ function is S-shaped and has got a flexus. Therefore a functional form that is compatible with this specific conditions is:

$$N(t) = \alpha 1/1 - e^{-kt}, \tag{15}$$

where k measures the speed of the process. Equation (15) equation has its solution in the standard logistic function.

The interpretative framework implemented so far is consistent with the empirical evidence. As it is well known, a large empirical evidence suggests in fact that the time profile of the diffusion of a technological innovation and a family of closely related technological innovations can be easily approximated by a logistic distribution which exhibits a long phase of slow progresses, a period of fast adoption by new firms and eventually a stretched period of approximation to the asymptotic levels of saturation (Stoneman, 1983, 2002).

The process of diffusion of a new technology can now be considered as the rational result of the dynamics of localized creative adoptions engendered by the continual mismatch between plans and actual market conditions. The rate of the diffusion will be influenced by the dynamics of adoption costs and gross profitability of adoption, but also, by the dynamics of localized technological change. When the mismatch between plans and actual market conditions is wide for many firms, when the effects of irreversibility are strong and hence switching costs are relevant, when technological opportunities are attractive, the inducement to change the technology will be stronger and hence the incentive for creative adoptions. As a matter of fact innovation and adoption are likely to feed each other so as to be complementary aspects of a broader dynamic process. The larger is the number of firms that do change their technology by means of varying degrees of creative adoption and the wider is likely to be the mismatch between plans and actual market conditions. Hence the stronger is likely to be the incentive to adopt and innovate. The diffusion process of a given family of technologies will be faster, for given dynamic paths of its gross profitability of adoption and adoption costs, the larger is not only the net profitability of adoption, but also and primarily the incentives to change the technology in place.

The variance in the speed of the diffusion process of a given family of innovations, across countries and regions, with similar structural characteristics, and a similar distribution of asymmetries among firms in terms of cost conditions and access to information, can be explained by the variance in the levels of entropy in factor and product markets and hence in the strength of the levels of inducement for firms to change their technologies. The higher is the entropy in fact and the stronger are the incentives to change their technology, and the faster is the diffusion of a given family of technologies. The localized introduction of new technologies will take place also by taking advantage of the adoption of available innovations.

This model provides an analytical account which is consistent and compatible with the 'encompassing model' proposed by Karshenas and Stoneman (1995). Karshenas and Stoneman have elaborated an equilibrium model of diffusion able to take into account of both demand and supply side factors and their interrelatedness. Like the model presented here, their encompassing model is very flexible to incorporate several types of costs of new technology. At one extreme: purchasing a capital good only; at the other end: a whole set of factors such as costs of learning, switching, upgrading human capital stock, changing the organization. This model in other words elaborates a frame to understand the decision-making of firms which is likely to generate expected dynamic behaviors that are well represented by the variety of cases integrated by the flexible model of Karshenas and Stoneman (1992, 1995).

Conclusions

The economics of localized technological change provides a context into which the adoption of new technologies can be considered as the result of an active and intentional undertaking of firms. The adoption of a new technology is the result of a complex process where an inducement mechanisms has to be identified, specific activities have to be put in place, dedicated resources have to be committed. The adoption of a new technology requires a clear effort to adapt it to the pre-existing context. There is no adoption without adaptation. In turn such an adaptation requires considerable levels of competence and creativity.

At the same time the introduction of a new technology is always the result of the blending and recombination of elements of technological knowledge both as a good and embodied in capital goods and intermediary inputs, organizational procedures and routines introduced elsewhere. Each innovation as a matter of fact builds upon previous innovations. Technological knowledge and technological change as a consequence exhibits strong elements of 'cumulability' and both are the result of the incremental introduction of changes added on to previous advances. If there is no adoption without adaptation, it is also true that there is little innovation without some adoption.

The economics of localized technological change provides a context into which the inducement to introduce technological changes is the result of the creative reaction of firms exposed to an increasing gap between expectations and actual conditions of profitability. When technology has to be changed, because switching costs impede standard shifts in the existing maps of isoquants and performances are falling below the expected levels, firm can rely on their competence and the knowledge acquired by means of research and development activities carried on intramuros. External sources of knowledge and new technologies embodied in new capital goods and intermediary inputs however do provide essential inputs to the introduction of new technologies by each firm. The introduction of technological change is the outcome of a process of creative adoption where external knowledge and new technologies made available in the markets are recombined with the knowledge generated internally by means of learning processes and research and development activities.

The traditional divide between innovation, adoption and diffusion can be successfully questioned in the context of the economics of localized technological change. Firms are induced to change their technology when product and factor markets conditions do not meet their expectations and irreversible choices make adjustments expensive. Technological change is the result of the combination of research and search activities that lead to both the introduction of new technologies and to imitative adoptions. Both command resources and engender specific revenues. Localized technological change consists of creative adoption where external knowledge and embodied technologies are implemented with internal competence and idiosyncratic knowledge acquired by means of learning processes. The identification of the net profitability of adoption as defined by the gross profitability of adoption minus adoption costs contributes the economics of technological change. The analysis of the evolution of the net profitability of adoption in the context of the economics of localized technological change shows that the dynamics of creative adoption is able to generate a S-shaped diffusion path at the aggregate level.

The divide between innovation and adoption is less and less realistic at a time when general-purpose technologies (Helpman, 1998), such as new information and communication technologies, characterize the rate and direction of technological change. New information and communication technologies with high levels of fungeability characterize the present trend of innovation at the aggregate level. In this context, firms, induced to change their technology by the dynamics of localized technological change, make use of the fungeability of the new technological system and enter a process of creative adoption.

Adoption and innovation are two complementary aspects of a broader process of reaction to the mismatch between expectations and facts and eventual introduction of localized technological changes that build upon the creative adoption and recombination of internal and external technological knowledge.

The distinction gross and net profitability of adoption and the identification of the costs of adoption together with the grasping of their dynamics, including the effects of the stocks of adoption on the evolution of the net profitability of adoption, provides an analytical probe that combines the demand and supply tradition of analysis of diffusion and shows the complementarity between innovation and adoption within the context of the economics of localized technological change.

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Notes

1. See Nathan Rosenberg: "The criticisms which I have leveled thus far against the artificial segregation of invention from innovation apply equally well to the segregation of invention from diffusion. Innovation is simply the beginning of the diffusion process. However, here again we have inherited from the Schumpeterian framework a sharp disjunction that emphasizes the high levels of leadership and creativity involved in the first introduction of a new technique as compared to the mere imitative activity of subsequent adopters. Here also, as a result, the analysis of the diffusion process fails to focus upon continued technological and engineering alterations and adaptations, the cumulative effects of which decisively influence the volume and

the timing of the product's sale. The diffusion process is typically dependent upon a stream of improvement in the performance characteristics of an innovation, its progressive modification and adaptation to suit the specialized requirements of various submarkets, and the availability and introduction of other complementary inputs which affect the economic usefulness of an original innovation'' (Rosenberg, 1976, p. 75).

2. Actually only new solutions beyond E_3 can engender an actual increase in total factor productivity (see Antonelli, 1995, 1999).

3. The firm can 'discover' to its surprise that the equilibrium amount of possible adjustments makes it possible to introduce a total factor productivity increasing technological change, which leads the firm beyond equilibrium point E_3 (see Figure 1). This is clearly a case for procedural rationality as opposed to substantive rationality (Simon, 1982).

4. R_F is set by the amount of resources the myopic firm, unable to anticipate the 'technological surprise', should in any case invest in order to switch.

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