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Diffusion of innovations: Theoretical perspectives and empirical evidence

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This paper attempts to review the theoretical and empirical perspectives of innovation-diffusion literature. The objective of this paper is to develop a heuristic framework by reviewing the existing studies for analyzing the diffusion of innovation and its outcome in different sectors. The formal theoretical and empirical literature on technology diffusion that emerged in the fifties with the epidemic approach has been followed by a voluminous literature spanning different disciplines. From the different strands of literature on analyzing the process of diffusion, the paper finds that there is considerable heterogeneity within theoretical approaches with respect to the process of diffusion. It seems that innovation and diffusion are a complex process that hinges inter alia upon the nature of innovation, adopters' characteristics, institutional context and that all these vary over the time and space.

Keywords: adopters' characteristics, innovation, institutional context, technological diffusion

Introduction

The theoretical discussion on diffusion can be traced back to Schumpeter's linear progression, beginning with invention to innovation and then to diffusion. Technology diffusion is considered as the third pillar along with invention and innovation of the process of technological change.[1] Both invention and innovation are considered as the precondition for the development of new technology, but it is diffusion that brings out the technological dynamism of the economy through productive uses of the innovation. Rogers and Shoemaker (1971) defined technology diffusion as the process by which an innovation or idea is communicated through certain channels over time among the members of a social system. Stoneman (1983) described the concept of diffusion as follows: let's consider a new product, i.e. consumer durable goods and D^* as its post diffusion level. Further let D_t be the stock that households own in aggregate at time t. The diffusion problem concerns how D_t tends to D^* over time. If diffusion is instantaneous, then $D_t = D^*$ for all t. In any other case, D_t may differ from D_t^* for any t and when the percentage use is plotted against time, the diffusion pattern follows an *S*-shaped curve.

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The remaining sections review these studies wherein we begin with an overview of different theoretical perspectives followed by empirical studies on diffusion as well as its outcome. Drawing inference from these studies, the objective of this paper is to develop a heuristic framework for analyzing the diffusion of innovation in different sectors. The study also attempts to provide an understanding how diffusion of innovation is traditionally understood in various disciplines.

Theoretical perspectives and empirical evidence

Diffusion of innovation is discussed in various theoretical approaches and it is not confined to any specific discipline. To achieve a comprehensive understanding on diffusion, the paper presents an overview of the tradition of diffusion research followed by different theoretical perspectives. In sociology, diffusion is understood as how some specific items, either an idea or a practice, have been received either by individuals or groups over time in a social structure and culture (Katz, Levin, and Hamilton 1963). Sociologists consider time and rate of acceptance as the major factors for diffusion while they consider date of first use as the measure of acceptance. However, anthropologists differ and are sceptical about the fact that whether an item is adopted in the same manner or not across different societies (Katz et al. 1963). Regarding the adoption of any innovation across different societies, anthropologists wanted to know whether that innovation is same or not. Other than sociology and anthropology, innovation-diffusion is widely discussed in economics. Invention, innovation and diffusion are considered as the three pillars of the theory of technological change and Schumpeter is considered as the father of the study of diffusion. However, epidemic approach is considered as the starting point of most of the diffusion research. Hence, the paper started the theoretical discussion with a brief overview of epidemic approach followed by other approaches. A brief discourse on all theoretical literature will provide an understanding on the diffusion process, factors affecting it and its outcome across different sectors.

Epidemic approach

The process of technology diffusion under the epidemic approach compares the process with contagious diseases. The approach emphasizes that the adoption of a technology spreads like an infection among the potential adopters. By taking a homogeneous group of potential adopters as an assumption, it explains the adoption of any innovation. At the initial stage, the technology is adopted by a few potential users. Over time, non-users come across users and interact with them. By interacting and mingling socially with users, the number of non-users declines, and they become users. Basically, the interpretation of this is that the transfer of information from users to non-users leads to the diffusion process, while the proposition is if the growth of users is plotted over time, then it will map out an S-shaped curve, which is a standard logistic curve (For more details see Stoneman 2002). To summarize the discussion, first, here the diffusion process is self-perpetuating as initial use stimulates further use. Second, it follows a disequilibrium path as the level of users is always lower than the number of potential users (Stoneman 2002).

This approach has gained popularity in disciplines like sociology, geography and marketing; however, it is criticized by various economists not only for its weak theoretical foundation but also for its restrictive assumptions. The criticisms are mainly based on the fact that although the approach gives an idea of aggregate (industry or household) behaviour, it does not focus on the individual's (firm or household) adoption process. Based on this argument, Jensen (1982) pointed out that the approach does not explain why some firms adopt innovation faster than others. In addition, this approach is criticized for its assumption of inter-personal contact and the existence of homogenous populations. The argument from this view is though the model assumes homogeneous and unitary groups of potential adopters, there is a possibility of non-mixing sub-groups. Hence, there is a possibility that non-mixing sub-groups may restrict information spreading before the completion of diffusion. In addition to this, Davies (1979) criticizes the model, noting that in the presence of mass media, depending on personal contact for information dissemination is quite unrealistic. Mansfield (1961) criticizes the model mainly because of uncertainty regarding the performance characteristics of new technologies rather than owing to the receipt of information. He contends that the performance of new technologies is challenging. Hence, he introduced a model wherein uncertainty is reduced over time as a result of learning from experience. In addition to this, Stoneman's (2002) criticism is based on clarity of information. He asserts that though information drives the use of technology, there is no clear-cut definition of information. The information could be related to either the existence or the performance of technology. The argument is that potential adopters may know about the existence of technology; however, the lack of information on performance of technology may limit its adoption. Hence, information on both existence and performance plays an important role in the diffusion process. In the case where potential adopters are not adopting new technology because they lack information on the performance of that technology, then they need to actively search for the information rather than wait for passive information. Further, the approach is criticized as it assumes that change in price does not have impact on the diffusion process which is impractical (Stoneman 2002).

As the criticisms endured, there has been substantial diffusion research that has come up with new theories to provide answers to questions like why individual firms (household) take time to adopt a new technology. One of those theories is by Brown (1981) who discussed the differential rate of adoption and its underlying process through different perspectives of technology diffusion. He added to the theoretical discussion by including additional factors over and above the interaction among potential adopters. He assessed the diffusion process and concluded that the reason for the differential rate of adoption is mainly due to individual characteristics (adoption perspective), role of diffusion agencies (market and infrastructure perspective), and continuity of innovation (economic history perspective).

Adoption perspective

Under the adoption perspective, Brown focused on the individual characteristics in order to understand the diffusion process (Das 2010). By analyzing individual characteristics, the perspective stresses the demand aspects that determine the diffusion process. The adoption approach basically points out that learning and communication processes and factors that facilitate effective flow of information are vital for the adoption of new technology. Like the epidemic approach, it also calls attention to the interaction among potential adopters in the diffusion process.

The adoption perspective is also described by Rogers and Shoemaker (1971). They explained that the innovation-diffusion process follows five stages:[2] awareness, interest, evaluation, trial, and adoption. The fifth stage of their theory talks about the adoption; however, the critics point out that there is a possibility of rejection as well. Hence, the adoption process should involve only two stages: awareness and adoption. There is every possibility that an individual or firm might reject an innovation anytime during or after the adoption. To overcome these criticisms, Rogers changed the terminology of the five stages to: knowledge, persuasion, decision, implementation, and confirmation.

Market and infrastructure perspective

Other than demand side factors, another set of factors that are important for diffusion is the way innovations are made available to potential adopters. Until innovations are available among potential adopters, it is difficult for them to adopt. The market and infrastructure perspective deals with this aspect rather than with adopters' characteristics. This perspective assumes that all potential adopters do not have an equal opportunity to adopt the innovation, which is needed to facilitate the diffusion processes. Hence, three actions are important. The first is that the establishment of diffusion agencies whose role should be to disseminate the innovation among potential adopters. This could be achieved either through a centralized or a decentralized structure, with or without a propagator. The second assignment after establishing the diffusion agencies, is to develop and implement the strategies to facilitate adoption. There are number of strategies available, four of which are important strategies required for diffusion: (i) development of infrastructure and organizational capabilities, (ii) price structure for the innovation, (iii) promotional communications and (iv) market selection and segmentation. The third action is implementation. To sum up, this perspective emphasizes the role of diffusion agencies in inducing the adoption of innovation among potential adopters.

Economic history perspective

Both 'adoption' as well as 'market and infrastructure' approaches are static in nature, as both the approaches assume that innovation is same throughout the diffusion process. Critics point out that any innovation in its lifetime can hardly remain same throughout the diffusion process because the environment in which it evolves is always changing and it follows a dynamic path. On this basis, economic historians developed a dynamic approach of innovation that is divided into the traditional interpretation of economic history and the reinterpretation of economic history. The former deals with the preconditions of diffusion whereas the latter discusses the continuity of innovation. Basically, the first school shows more concern with the invention than with the diffusion process; however, the reinterpretation of economic history focuses on the continuity of innovation which affects the temporal as well as spatial pattern of diffusion from both a supply and a demand viewpoint. Regarding the supply point of view, location and timing of the supply of new technology (or innovation) and its adoption have significant bearing for potential adopters. However, on the demand side, even if innovations are available, sometimes potential adopters might prefer to delay their adoption with the expectation that there will be further improvements in the innovation.

In addition to these two perspectives, there are other studies that attempt to overcome the limitations of the epidemic approach. Metcalfe (1988) introduced two different starting points which were ignored in the epidemic approach. One characterizes the mechanics of the diffusion process while the second characterizes the decision-making procedures which drive the diffusion process. These two distinct points are further elaborated by Sarkar (1998) who asserts that in the former the diffusion process is an equilibrium process and over time this equilibrium shifts. However, regarding the latter, the concern is whether the potential adopters should be modelled as fully informed or if they are constrained by a lack of information. By combining these two issues, Sarkar (1998) constructed four models: the full information equilibrium models; the limited information equilibrium model; the full information disequilibrium model; and the limited information disequilibrium model. The full information equilibrium model leads the neo-classical approach while, owning to its open-ended nature of decision-making, the limited information disequilibrium model leads to evolutionary theory (Das 2011). The following section deals with these models.

Neo-classical approach

The neo-classical approach or full equilibrium approach focuses on full information about an innovation. Unlike the disequilibrium approach, here the assumption is that rational adopters have complete information about an innovation; that is, on the existence of as well as the features of new technologies, across all points of the diffusion path. Hence, the epidemic model has no role to play in the diffusion process. Metcalfe (1988) highlights some essential features of this approach, the focus of which is that the diffusion pattern of any innovation depends upon the heterogeneity of potential adopters and a differentiation between objective and perceived benefits of adoption. In this approach, models are classified as a probit approach (Davies 1979) and game theoretic models. Further, these models have also been explained as rank (probit), stock and order effects (Karshenas and Stoneman 1993).

The rank (probit) approach assumes that potential adopters are not homogeneous but, rather, that they differ from each other. Due to this heterogeneity of potential adopters, some adopters acquire higher gross returns from the innovation than others. Hence, there is a possibility to rank all the adopters as per the benefits obtained from the new technology. As users can be ranked in terms of their benefits, the models are also known as rank effect models (Karshenas and Stoneman 1993). The theory of technique choice highlights that in the absence of uncertainty, the potential user will purchase technology if gross benefits exceed the cost. The rank approach assumes that the cost of acquisition in a definite time (t) needs to be same for all members of the population. Let us assume cost of acquisition in the time period t is C_t and the benefit in time t is b_i. The acquisition rule says that a technology is acquired by the adopters if b_i is either greater than or equal to C_t. Hence, depending upon the size of the benefits, the entire population could be divided into two categories: adopters who get positive benefits ($b_i > 0$) and non-adopters who obtain negative benefits ($b_i < 0$). The adopters, having positive benefits will adopt the innovation in time t and they will be equilibrium level of adopters for that period. However, this will not generate the diffusion path. This only shows the proportion of the population who own the technology in time period t. The diffusion path will be generated when there is a change in the ownership of the technology in time t. Now the change in ownership can occur either through change in cost of acquisition C_t over time or change in gross benefits over time. Hence, the speed of diffusion depends upon both the rate of change in benefits and costs. The final level of use is determined when benefits and costs stop changing. It needs to be pointed out that in a case where all users face the same costs of acquisition at a point of time, then the early users will get higher gross benefits than the late users. The principle also identifies other factors that lead to the diffusion path. These include size, location, history; discount rates or attitude to risk; price, technology and market expectations; the number of product variants on the market; and the overall changes in all these factors (Stoneman 2002).

Compared to the epidemic approach, the rank approach is in a better off position and contributes significantly to the theory of diffusion. Unlike the epidemic approach, the model is not self-propagating because at each point of time the number of adopters creates an equilibrium level of users of that technology. In the rank approach, the return to a firm from adopting a new technology is assumed to be independent of its own use and the number of other of users that technology. However, this assumption is not always accepted, and hence alternative models have been established.

One of the other limitations of the epidemic approach is that it lacked behavioural explanation of potential adopters. Hence, alternative explanations like the game-theoretic approach have been proposed. The game approach basically stresses strategic behaviour of all potential adopters and discusses the optimal time to adopt an innovation (Sarkar 1998). *Stock* and *order* effects are two alternative approaches discussed under game-theoretic approach. The first one assumes that with the increase in number of adopters, the marginal benefit from acquisition declines. Further the stock effect assumes that over time there will be fall in cost of acquisition. This fall in cost results in new adoption which creates the diffusion path. Compared to this, order effects assume that early adoption of any innovation results in higher return from that technology. Like stock effects, here the assumption is also that over time cost of acquisition falls and new adoption leads to the diffusion path. This theory has been popularized by Reinganum (1981) and Quirmbach (1986).

Reinganum (1981) in her study examines the diffusion of process innovation. By examining the capital embodied process of innovation, she claims that diffusion is purely strategic behaviour. She assumes firms are identical in terms of their output, characteristics and costs. The Reinganum approach can be explained as follows:

> Suppose the old technology is generating cost per unit of output as named C_0 and the new technology costs per unit of output C_1. The annual profit for the user of old technology in time t will be $\pi_0(t) = (P(t) - C_0)q_0(t)$ while the profit of the user of a new technology will be $\pi_1(t) = (P(t) - C_1)q_1(t)$. Here $q_1(t)$ and $q_0(t)$ imply the output of the firm in time t by using new and old technologies respectively which are dependent upon price and costs. Hence, the difference in profit can be measured by taking the difference between the profit levels of two periods. Symbolically

$$\begin{aligned}\pi_1(t) - \pi_0(t) &= (P(t) - C_1)q_1(t) - (P(t) - C_0)q_0(t)\\ &= P(t)(q_1(t) - q_0(t)) - C_1q_1(t) - C_0q_0(t)\end{aligned}$$

Given the new technology is superior and the adoption of that will reduce costs, C_1 will be less than C_0. Hence, $q_1(t)$ will be greater than $q_0(t)$ and so $\pi_1(t) - \pi_0(t) > 0$. The underlying message of this model is that by undertaking the assumptions of strategic behaviour with oligopolistic market settings, perfect information and identical firms, there will be diffusion of new technology rather than simultaneous adoption. As the number of users increases along the diffusion path, the industry price falls over time. This implies two things: first the profits of a non-user, then the profits of a user, decline. Relating to the size of elasticity of demand, the profits of a user fall faster than the profits of a non-user. Thus, in Reinganum's model, as diffusion proceeds, the difference in profits between a user and a non-user gets smaller.

Like Reinganum (1981), Quirmbach (1986) first examined the factors that cause the diffusion of a capital embodied and cost reducing innovation. Following Schumpeter, he also attempted to explore the effect of market power on the diffusion rate in the capital equipment market. Some of the findings of his study are similar to those of Reinganum (1981). For instance, he shows that the diffusion of a capital embodied process of innovation results from a pattern of decreasing incremental benefits and adoption costs for later adoptions. However, in his study, strategic behaviour has not come up as an essential factor for the diffusion process. Rather incremental benefits and adoption costs are the key factors. Other than that, the study also finds the role of market power in order to determine the diffusion rates.

The order model proposed that it is not always acceptable that as more firms use a new technology, the profits of users and non-users decline. Fudenberg and Tirole (1985) argued that the profits from the adoption of any technology depend on the order of the adoption. They pointed out that being a first user may generate higher profits for the user over the whole lifetime of the ownership of the new technology. The rationale for this may be based on several grounds. One possible reason is that there is high possibility that early adopters can pre-empt certain inputs in the fixed supply like best geographical location or skilled labour (Ireland and Stoneman 1985). Another possible reason is that the first adopter can enjoy first mover advantage; that is, the first mover has the ability to take actions that can affect the adoption decision of other firms (Stoneman 2002). The model considers the net present value of a new technology as being related to the number of other users at the date of adoption and there exists an inverse relation between the two (Stoneman 2002).

Evolutionary approach

The theory of technological change can be traced back to Schumpeter which has three stages: invention, innovation and diffusion. The theory, inspired by Darwin's evolutionary theory (1859), defines technological change as a process that destroys old systems that are replaced by new ones. Originating from the theory of technological change, the evolutionary approach does not distinguish among different stages of technological change; hence, it can be applied to any of these stages. The approach rejects full information and disequilibrium diffusion process. Decision-making in this approach need not be necessarily continuous and based on profit maximization. Though there are number of contributors to evolutionary approaches (Witt 1991; Hodgson 1993), one fundamental concern always prevails. These approaches together represent a change in perspective from the equilibrium approach. The propagators of evolutionary approach have two central concerns: one is the process that determines the range of available innovations and the second is the processes that alters the relative contribution of different innovations to economic welfare (Metcalfe 1995). In contrast to the equilibrium theory of innovation, here the basis is an explicit behavioural approach in which decisions are routine-based and can be expressed in terms of identifiable rules of thumb (Metcalfe 1995).

The underlying effects of the evolutionary approach deliberate that diffusion does not occur because of the replacement of old technology with new technology; rather, it occurs as a result of competitive selection across technologies (Metcalfe 1988). The driving opinion is that at any time multiple technologies are available and potential adopters can choose any of these.

Hence, continuity of innovation either through creativity or variety is vital in this approach (Metcalfe 1995). The basis of the approach is that with the increase in the number of users of any technology, the benefit to a user compared to a non-user declines. This approach in the literature has been mostly used to explain the adoption of process technologies by a firm; however, Stoneman (2002) asserts that the approach can be applicable to households through network externalities.

Systems of innovation

Systems of innovation comprise 'all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovations' (Edquist 1997, 14). Though historically the concept was introduced by Friedrich List (1841), the modern version was acquainted by Lundvall (1985). However, Freeman (1987) popularized this concept and provided it with international credibility when he analyzed the economic performance of Japan. He defined a national system of innovation (NSI) as 'the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies' (Freeman 1987, 1). Since then, there has been a voluminous amount of literature focusing on innovation and diffusion using the innovation system perspective (Nelson 1993; Freeman 1987; Lundvall 1995; Edquist 1997). The framework asserts knowledge as the most fundamental resource of the economy and that it can be acquired through interactive learning where in institution can play a major role (Participants of the training programme on innovation and development, 2015). Interaction among different actors in the system[3] leads to interactive learning and capacity building which results in development and diffusion of new technologies. To make national innovation systems effective, the state should play a vital role as it can facilitate appropriate institutional architecture and formulate as well as implement policies.

This approach deviates from the conventional linear approach to technological change and considers innovation as an interactive process for economic development and welfare. In this respect, it focuses on interdependence and non-linearity, with institutions playing a central role (Joseph 2006). Institutions, being the core component of this approach, have different meanings for different authors. Nelson (2008, 2) unified the term institution and asserted that all writings on the system of innovation sheds light on the character and factors supporting generally used ways of doing things in contexts 'where the action and interactions of a number of different agents determines what is achieved'. As discussed, the literature is essentially concerned with the process of learning within the firm and in its interaction with other organization in the system (Cozzens and Kaplinsky 2009). Other than institutions, learning and interaction are considered as the core concepts of the NSI framework. The framework consists of various actors as its analytical units and capacity or competency building among these actors is the object of analysis. To develop capacity and competence, action and interaction among these actors are required. This action and interaction are governed by the institutions. Building of competence is essential not only because it generates income over time, but also because it affects growth as well as distributes income in different ways (Lall 1992; Cozzens and Kaplinsky 2009).

The preceding discussion on alternative approaches to technology diffusion emphasizes the process of diffusion. It explains various factors that determine the diffusion of innovation and rates of diffusion in terms of differences in individual behaviour. In the following sections, we discuss the process of diffusion and the theories related to diffusion and its outcome.

Diffusion and its outcomes

Rogers and Shoemaker get the credit for taking up the pioneering study on the outcome of innovation-diffusion in 1971 (Das 2013, 2015). Following their work, it is widely accepted that that innovation-diffusion improves individual welfare, and enhances economic development and social change (Brown 1981; Rogers 1983). Rogers and Shoemaker (1971) stressed that diffusion of technology is instrumental in ushering in social change and considered the 'consequences' of innovation as the third step of the process of social change resulting from invention and diffusion. Consequences[4] in their study are nothing but the differences that have taken place within a social system owing to the adoption or rejection of innovation. Changes or differences in the social system could bring about desirable consequences, which are functional or undesirable (dysfunctional) consequences. Whether the changes are functional or dysfunctional depends upon the adopters and the time of adoption of the innovation. For example, the adoption of an innovation might be beneficial to certain sections of society but might create very different implications for society as a whole. The early adopters derive windfall profit,[5] while laggards are influenced through economic pressure and hence forced to adopt. The adoption of any innovation might necessarily not have any direct impact upon adopters but might have indirect consequences.[6] Hence, it can be concluded that diffusion literature pays insufficient attention to the impacts of diffusion for three alternative reasons. First, the leading research institutions focusing on diffusion research emphasize adoption per se with the implicit assumption that diffusion will bring in positive results for social change. Second is the survey data. Measuring consequences primarily relies on survey data, while the general survey method might not be appropriate to measure the consequences of diffusion. Third, consequences are difficult to quantify because, by and large, adopters are not aware of several consequences. The respondents' reports are mostly qualitative information that might carry individual biases. An additional challenge in measuring the consequences of an innovation is that consequences are commonly cofounded with other effects. For instance, in order to assess the impact of adoption of improved seeds on crop yields, the influences on other inputs like fertilizer application, pesticides and any other inputs cannot be ignored. In their discussion, the authors have proposed a new model for measuring the consequences, in which the key dependent variable should be explained as consequences.

Similar to Rogers and Shoemaker, Brown (1981) explained alternative perspectives of diffusion. The author discussed the impact of diffusion as development perspective of diffusion. The perspective provides a two-way relationship between innovation-diffusion and social change and answers two inter-connected questions. The first is the social and economic change brought about by the diffusion of innovation, while the second is the influences of development process on innovation-diffusion. Basically, the latter explains how the development indicators of an economy like infrastructure facilities affect the diffusion process. Similar to Rogers and Shoemaker, Brown has shown that early adopters gain windfall profit. However, he named it 'adoption rent'. This puts pressure on non-adopters as it steepens competition in the market.

Technology diffusion: Empirical evidence

Following all these theoretical arguments, a series of empirical studies have been taken up to analyze the diffusion process. The empirical studies on technology diffusion are not limited to the discipline of economics, but expands to other streams of the social sciences. For instance, the spread of rumours, the adoption of new drugs, new teaching methods and use of steel axes by tribes have all been the subject of investigations by sociologists, medical sociologists, educationalists and anthropologists, respectively (Rogers 1962). It is best represented in geography by the work of Hagerstrand in 1953. However, most of the studies have used the common analogy of the spread of diseases that is the epidemic approach to diffusion. This theoretical framework of the epidemic model has formed the common introduction to a vast body of empirical research and has been commonly used in research to explain the diffusion of farm, production and household technologies (e.g., Griliches 1957; Bain 1962). Later, it was extended to the equilibrium approach to diffusion (Davies 1979).

To the best of our knowledge, the first-ever empirical study was undertaken by Ryan and Gross (1950), who analyzed the diffusion of hybrid corn seed in two Iowa communities. Their study analyzed the time pattern that the communities followed to adopt the hybrid seed. Most of the adopters first experimented with small quantities of seed before expansion. A slew of factors like size of the farm enterprise, education, youthfulness and the extent of social participation determined the early adoptions. After Ryan and Gross, Griliches (1957) used the epidemic model to explain the diffusion of hybrid corn among USA farmers. Griliches fitted a logistic growth function to show that regional differences in the time of innovation and the rate of adoption could be explained by economic variables such as expected profits and sale. At the same time, he also showed that the variation occurred in the initial phases as it depended on the speed with which the seed was customized to different geographical settings. This implies that diffusion also depends upon the role of suppliers of a particular technology in understanding the needs of different local conditions. In a similar vein, by using the epidemic approach to technology diffusion, Mansfield (1961, 1968) analyzed the diffusion of number of industrial innovations. Using a simple model, he explained the differences in the rate of imitation among different innovations. The author found that innovations with higher profits and relatively lower investment requirements increase the rate of imitation. In order to examine the growth of television ownership in UK, Bain (1962) adopted the same epidemic approach. Estimations were done at quarterly intervals 1959 in different areas in England and Wales from the third quarter of 1952 to the second quarter of 1959. During this time period, in addition to four major transmitters, a few low-power transmitters like the British Broadcasting Corporation (BBC) and Independent Television (ITV) came into operation. The theoretical assumption of the model led to a modified logistic growth curve where the saturation parameter is the function of the programme features of the area, hire purchase deposit requirements and a cross section measure of average income levels. The analysis of the results showed that both the introduction of ITV and changes in credit restriction had a considerable influence over the saturation level of ownership. Another study on technological change and the demand for computers by Chow (1967) drew similar inferences. The study argued that the diffusion of any technology depends upon the quality of that particular product. By explaining the growth of computers in the United States between 1955 and 1965, Chow illustrated that two elements accounted for the rise in the use of computers. First, without quality change it takes time for a new product to reach the equilibrium level. Second, in the meantime, as the quality of the product improves, the equilibrium level also soars.

In contrast to these studies, Davies (1979) analyzed the mechanization of harvesting crops in the US in the nineteenth century. American farmers did not own sufficient acreage to use the labour saving technology and farmers were not in a position to pay for the initial outlay required to install reapers. This was the reason behind the slow adoption of mechanized reapers. Diffusion rate of reaping technology only increased when prices fell relative to wage rates and increases in farm sizes. The study on diffusion of steamboats by Mak and Walton (1972) during 1815–1860 showed the dramatic effect of technological change in inland transportation. The objective of the study was to measure productivity changes in steamboating on western rivers during the antebellum period and to determine the sources of productivity advance that occurred. The introduction of the steamboat brought about an impressive surge in the productivity of inland water transportation. It also marked the eclipse of keel boating as it led to a significant fall in freight costs. The absolute and relative fall in real freight costs paved the path for successful diffusion. Another study argued that installation of related equipment or infrastructure is important determinant for diffusion. David (1989) examined the use of electric power in the manufacturing industry. The results indicate that it took over 40 years for the complete diffusion of electric power in the United States. The installation of electric power in a factory required redesigning of layout and alteration in task allocation.

A comparative study on the UK and Italy undertaken by Battisti and Stoneman (1998) explained the role of institutions in the diffusion of unleaded petrol. The changes in taste and price differences (price differences are mainly due to different fiscal incentives) are the major factors behind shaping the diffusion pattern. In both the countries, taste factors dominated the diffusion pattern. The estimated model by the authors showed that other than the trend or taste effects, the regulation on using unleaded fuel was also important for differential diffusion pattern. Given the emerging pattern of tastes in the UK, the market is naturally tending to a high level of use of unleaded fuel in contrast to Italy. A study by Ferrence (2001) discussed the applicability of the diffusion model in understanding drug-related behaviour. The study, which focused on the use of alcohol, tobacco and illicit drugs, found that drug use with its global spread and susceptibility to market forces is an appropriate subject for applications of the diffusion model.

In the recent years, a large number of studies have been undertaken on the diffusion of information and communication technologies (ICTs) and the factors that influence the diffusion of ICTs across regions and countries. Earlier studies, dealing with developed countries, mostly focused on internet diffusion. Of late, the focus in the context of developing countries has been moving towards more than one indicator of ICT. Such studies have listed a host of variables that affect the diffusion of ICTs. Broadly, empirical studies emphasized three sets of factors: adopters' heterogeneity, technology and institutional factors. Several characteristics of adopters like income and education influence the diffusion of ICTs. More precisely, the studies point out the following demand side variables: GDP per capita or income level of potential adopters (Canning 1999; Hargittai 1999; Norris 2001; Kiiski and Pohjola 2002; Baliamoune-Lutz 2003; Dasgupta, Lall, and Wheeler 2005), education (Hargittai 1999; Caselli and Coleman 2001; Norris 2001; Robison and Crenshaw 2001; Kiiski and Pohjola 2002; Dasgupta, Lall, and Wheeler 2005), and population level (Canning 1999). Regarding technological characteristics, the studies have hinted at the following factors: technological infrastructure (Canning 1999; Guillén and Suárez 2001; Norris 2001) and access costs (Greenan and Guellec 1998; Canning 1999; Kiiski and Pohjola 2002). On the institutional front, institutional or policy factors (Guillén and Suárez 2001; Norris 2001; Dasgupta, Lall, and Wheeler 2005), political or trade openness (Caselli and Coleman 2001; Robison and Crenshaw 2001; Baliamoune-Lutz 2003), competition among the service providers (Hargittai 1999; Kiiski and Pohjola 2002), and regional dummies (Norris 2001) are highlighted.

Other than factors that influence the diffusion of technology, studies have also focused on diffusion of different technologies and its impact on different developmental outcomes like poverty reduction (Arunachalam 2004; Saith 2008; Tiwari 2008), easy access to markets (Abraham 2007), empowering women (Pillai and Shanta 2011) and rural development (Singh 2004).

Summary and conclusions

The discussion, so far, provides a comprehensive understanding of the process of diffusion on the one hand and factors that determine the process of diffusion on the other. Various factors like information on the availability and natures of technology, strategic behaviour, adopters' characteristics, costs and benefits from technology, growth of complementary technology, improvement in technology, the role of diffusing agencies, government policies and their strategies, and others are found to have a bearing on the diffusion process. Drawing insights from the literature, the framework depicted in Figure 1 is being developed for analysis of technology diffusion.

To elaborate, both the theoretical and the empirical literature emphasize different factors that lead the diffusion process. Those are learning and communication, adopters' heterogeneity, continuity of innovation, role of diffusion agencies in deciding price structure of the innovation as well as for promotional communication, infrastructural development and the role of institutions for interactive learning and capacity development. In order to have a clear-cut distinction among these factors, the present study again added these factors into three distinct groups: adopters' characteristics, technological characteristics and institutional factors.

The core of adopters' characteristics is the differential factors of the potential adopters that affect the diffusion of innovation. The adopters' characteristics could also be considered as the demand side factors that lead to the diffusion process. Similarly, the performance of technology could fall under supply side factors as the factors that relate to the technology itself. Performance of technology includes the nature and extent of improvement to the existing technology, which is the continuity of innovation. If certain technologies improve more quickly, with prices remaining the same or declining, then the likelihood of adopting such technologies increases. The second set of factors which comes under technology performance could be the availability of complementary or substitute technology. Other factors that relate to performance of technology could be its price or cost of adopting a particular technology. Other than these two broad groups of factors, the theoretical literature also emphasizes the role of government in building up infrastructure and the role of interactive learning and capacity building through institutional intervention. This study includes these factors as a distinct factor called institutional factors which can be adopted while studying diffusion of innovation in different sectors. For instance, if we are analyzing diffusion of innovation in the agricultural sector, farmers' characteristics like their educational level or whether they are trained in agriculture can be taken as adopters' characteristics or demand side factors. Since learning and communication comprise one of the major factors that determine diffusion, the demonstration effect or share of users can be considered as another variable under adopters' characteristics (Das 2014). At the same time, availability of alternative technologies (e.g., hybrid seeds) or improvement in existing technologies can be included under technological characteristics. Similarly, government's policy measures regarding use of technology and providing infrastructure

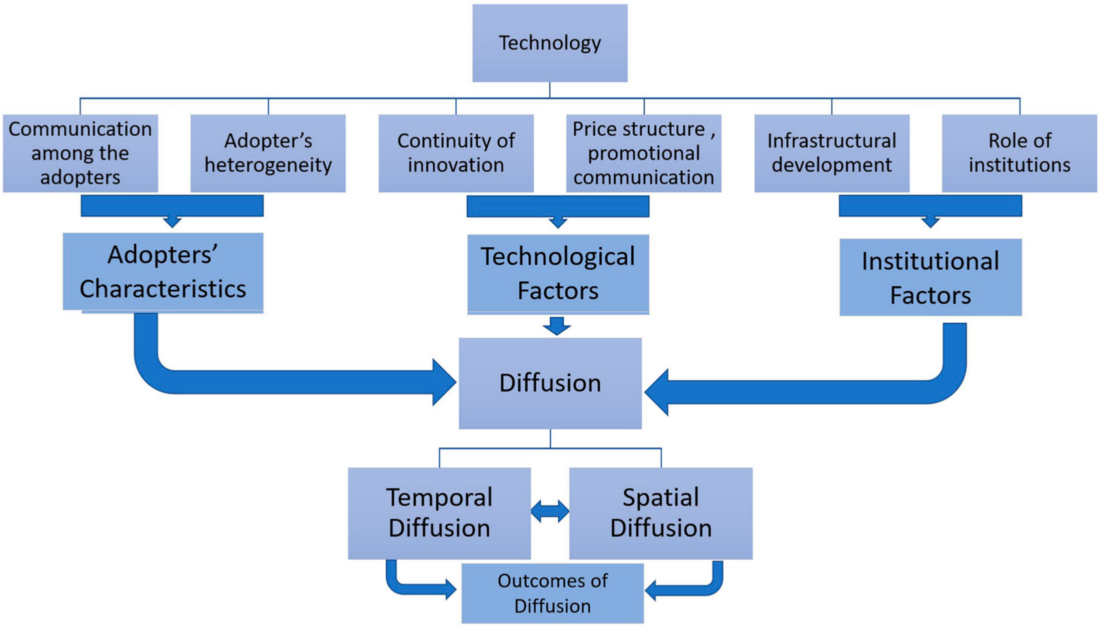

Figure 1. Various modes of technology diffusion

can come under institutional factors. These three broad groups of factors explain the diffusion process and differential rate of adoption across potential adopters (firms, households, regions, countries, etc.). The diffusion process, further, could be temporal and spatial diffusion or it could be both. Finally, the outcome of diffusion is experienced.

From the different strands of literature that analyze the process of diffusion, it appears that there is considerable heterogeneity within the theoretical approaches with respect to the process of diffusion. It seems that innovation and diffusion are a complex process that hinges inter alia upon the nature of innovation, adopters' characteristics, and the institutional context, and that all these vary over time and space. All the approaches have advantages with their own limitations, and the application and usefulness of each differs. However, in order to examine the process of any technology diffusion and its impact, a broader understanding of the ways that technology diffuses among potential adopters is essential. The present study proposes the integration of important insights from the studies highlighted in this paper to come up with a heuristic framework, which is developed by drawing different elements of all the theories and takes a complementary approach for the further analysis of technology diffusion.

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Notes

1. Technological change is defined as the advance of technology, such advance often taking the form of new methods of producing existing products, new designs which enable the production of products with important new characteristics, and new techniques of organization, marketing and management (Mansfield 1968). The first stage is the invention process, encompassing the generation of new ideas. The second stage is the innovation process with the development of new ideas into marketable products and processes. The third stage is the diffusion stage in which the new products and processes spread across the potential market.
2. When the individual learns of the existence of the new idea but lacks information about it is known as the adoption stage. Developing interest in the innovation and seeking additional information about it is the interest stage. For evaluation stage the individual makes mental application of the new idea to his present and anticipated future situation and decides whether to try it. In trial stage, the individual applies the new idea on a small scale in order to determine its utility in his own situation and finally in adoption stage, the individual uses the new idea continuously on a full scale (Rogers and Shoemaker 1971).
3. System could be national, regional or sectoral.
4. Consequences of diffusion are categorized as: functional versus dysfunctional, direct versus indirect and manifest versus latent. If effect is desirable, then it is functional; and if it is undesirable, then it is considered as dysfunctional. Similarly, direct versus indirect consequences depend on whether the changes in a social system occur in immediate response to an innovation or as a result of the direct consequences of an innovation. Finally, manifest versus latent consequences rely on whether the changes are recognized and intended by the members of a social system or not (Rogers and Shoemaker 1971, 17).
5. Windfall profits could be measured in social as well as economic terms. An example of social return could be the prestige that the innovator of consumer products may obtain by being the first to use a new idea (Rogers and Shoemaker 1971).
6. 'Direct consequences are those changes in a social system that occurs in immediate response to an innovation while indirect consequences are changes in a social system that occurs as a result of direct consequences of an innovation' (Rogers and Shoemaker 1971, 17).

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