The diffusion of innovations: some reflections

By

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Abstract: *This paper discusses a number of interrelated topics relating to the economics of innovation diffusion that merit further research and study. These topics encompass: how innovations are not just technological, may be horizontal or vertical, and may develop over time; the role in the diffusion process of complementarities across and substitutability between different technologies and innovations; how the many different sources of innovation other than R&D are given insufficient attention in the literature; the international dimensions of the diffusion process with emphasis on cross country effects; the role played by different market structures in the industries supplying goods embodying new technologies; the imbalance in the relative emphases upon intra firm and intra firm diffusion in the existing diffusion literature; the need for more research on the relationship between firm performance and the diffusion of innovations; and government policy on diffusion.*

JEL classification: O3; O4

Key words: complementarities; diffusion; firm performance; sources of innovation; international aspects; intra firm vs. inter firm; policy; supply side evolution.

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1. Introduction

This paper provides a personal commentary upon the current state of knowledge of the economics of the diffusion (i.e. the spreading of ownership and/or use) of innovations by exploring a limited number of issues that are of current importance in the field. This contribution is not meant to be either particularly innovative or comprehensive[1] but is designed to encourage others to consider the study of diffusion as a much wider topic than has often previously been the case. Being a personal reflection the bibliography is perhaps more slanted to my own past work than it would normally be.

2. Defining innovation

Deliberately this paper is entitled as relating to innovation diffusion rather than technological diffusion. The former is inclusive of the latter and thus a discussion of innovation widens the area of consideration. Technological change essentially comprises the introducing of new or significantly improved manufacturing or business processes and new products including (if defined widely) new services. In much recent work, in line with Organisation for Economic Cooperation and Development (2006), and as exemplified in the structure of the Community Innovation Survey, innovation is taken to also encompass non technological innovations such as implementing; new or significantly changed corporate strategies; advanced management techniques; major changes to organizational structure; and changes in marketing concepts or strategies. Recent literature in the field has explored these non-technological innovations more extensively (e.g. Bloom and Van Reenen, 2010, Ruigrok et al, 1999).

New products include both consumer products and producer products. The growth of demand for and ownership of consumer products has been more studied in the marketing

[1] More extensive reviews of the literature are Comin & Mestieri (2014), Stoneman and Battisti (2010), Stoneman (2002) , and Geroski (2000).

literature which has a long tradition of employing learning models of the Mansfield (1961) type as introduced by Bass (1969). The diffusion of process innovations, which has been most studied in Economics, is primarily the analysis of the growth of demand for and ownership by firms of new producer products, such products being the embodiment of the technology under study (e.g. computers, hybrid corn, robots, mechanical reapers etc.). The work of Comin and Hobijn (2009, 2004, and 2003) provides extensive historical data upon the spread across their potential usage of both new producer and consumer goods.

It is commonly observed that new technologies change over time. A characterisation is that an original new product embodying a new technology is first placed on the market but then, over time, further non-original but new-to-market products are also launched (by the originator or others) that embody further technological changes. One characterisation is that new products go through generations with later generations generally considered as superior to, and probably cheaper than, earlier generations. This raises a basic issue as to whether when studying diffusion one should study the diffusion of the innovation genus or the separate generations of that innovation (e.g. should one study the diffusion of computers in general or the diffusion of first, second, third, fourth etc. generations of computers separately). Current practice appears to mainly be to take the former approach rather than the latter. Under such an approach later improvements in the technology as embodied in new-to-market products may be seen as drivers of the diffusion of the generic technology.

Most of the discussion about how later new-to-market products drive diffusion relies largely upon an assumption that later products are superior in quality to earlier products. In this view, new-to-market products are considered better than existing products and preferred by all at the same price i.e. are superior, vertically differentiated, products. Such quality improvements encourage greater usage or ownership and will be seen to be driving the diffusion process. However it is possible that a new-to-market product is not superior to the existing product. It may be inferior but cheaper. Such a product can extend ownership of the generic technology by encouraging purchase by buyers with lower incomes, or less resources. In such a case lower quality may drive diffusion e.g. lower quality tablet computers at prices well below these charged by Apple have encouraged wider ownership of this technology.

In fact new-to-market products need not even be vertically differentiated from existing products; they may be horizontally differentiated (i.e. considered, at the same price, by some to be superior, but not by others). Such new products may be attractive to parts of the market not previously encompassed, and, in this way may drive diffusion, but it is not quality improvement that is the cause. Although there is a considerable literature that argues that quality improvements are a driver of the diffusion process, there is not an extensive literature that explores this formally using models of product differentiation, although Stoneman (1989, 1990) addresses diffusion and vertically and horizontally differentiated products and Stoneman, Bartoloni and Baussola (2018) considers this more extensively.

Much of the current literature addresses how innovation affects the functionality of products, for example speed, size, and memory capacity. However for a whole class of products these are not relevant characteristics – aesthetic characteristics such as appearance, smell, and sound are more important. This has led me to coin the term Soft Innovation to encompass innovation that impacts upon these other characteristics, which is especially (although not exclusively) important in, for example, film, theatre, publishing, food products, video games, and recorded music etc. (see Stoneman 2011, 2015). Such products can rarely be ranked vertically in terms of quality and new-to-market products of this kind, almost by definition, will be horizontally differentiated. Thus for the diffusion of such products it is horizontal product innovation that matters and not vertical improvements.

3. Complementarities and substitution in the diffusion process

Because new technologies may be substitutes or complements to each other, the diffusion of any one should be considered in frameworks that allow for the simultaneous adoption of others. Examples of such modelling are Battisti, Colombo and Rabbiosi (2015), Stoneman (2004), Stoneman and Toivanen (1997), and Stoneman and Kwon (1994). Without denying the importance of such cross technology effects there are also other possible complementarities that have figured less prominently in the diffusion literature. In particular, as described above, in addition to the introduction of new manufacturing or business processes, which one might consider as representative of the diffusion of new process technologies, there are other innovative activities taking place, namely, the introduction of: new products, corporate strategies, management techniques, organizational structures, and marketing strategies. There is strong evidence that the introduction of new processes are complementary with these other innovation activities (see, for example, Battisti and Stoneman, 2010, Brynjolfsson and Saunders, 2009, Mol and Birkinshaw, 2009, Frenz and Lambert, 2008, Black and Lynch 2004, and Milgrom and Roberts 1990). The analysis of the introduction by firms of new process technologies should thus be placed firmly in the context of their own and other firms' wider innovative behaviour.

Battisti and Stoneman (2013) provide some further empirical support for these arguments. Using a data set with special emphasis upon non-manufacturing and relating to 1497 UK enterprises in 2009 they observe the pattern of innovation activities detailed in Table 1. The most prevalent innovative activities are the introduction of new products/services (47% of the sample), new marketing techniques (45%) and new organisational structures (36%). New processes are being introduced by 34%. The pattern of innovation is quite heterogeneous across industries. These patterns clearly indicate that alongside process innovation other innovation is also occurring. Most relevant however, there are significant pair wise correlations across the different activities, for example, more than

50% of the firms that: (i) introduce new products and services also introduce new business processes; (ii) introduce new strategies also introduce new business processes; (iii) introduce new organisational methods also introduce new management methods; and (iv) introduce new marketing techniques also introduce new strategy, management and organisational techniques.

{Table 1 about here}

Using iterative principal factor analysis (IPFA) identifies two factors which account for about 90% of the overall heterogeneity in the overall innovation pattern: the first factor is driven by the extent of strategic, managerial, organizational and marketing innovations (labelled wider innovation); whereas the second factor is driven by the introduction of new products or services and new business processes is (traditional innovation). A two-step cluster analysis identifies 4 clusters of firms in the sample: The largest, comprising 57.5% of the sample, contains firms undertaking very low levels of both wide and traditional innovations; a second cluster (15.7%) has low levels of wider innovation activity but a high level of traditional innovation activity indicating complementarity between product and process innovation; a third cluster (12.8%) shows a high level of wider innovations activity and a low level of traditional innovations, indicating complementarity between the several different wider innovations; a fourth cluster (13.9%) has high levels of use of both activities indicating wide complementarity between all the different type of innovation.

Moreover, analysis across clusters shows that the sales growth of firms that undertake both traditional and wide innovations is greater than of firms that undertake either wide or traditional innovations alone or no adoption at all. This reinforces a view that at least some firms experience complementarities. The implication, in brief, is that the extent and timing of the adoption of new process technologies by firms will be at least partly a reflection of their overall innovative behaviour. To formally recognise this would be a step forward in the development of diffusion analysis.

4. R&D and other sources of innovation

Much of the innovation literature, and in particular policy discussion, has a tendency to associate technological (and other innovation) development with R&D alone. However, innovation may in fact arise from a number of different sources and these other sources should be given more prominence than has often been the case, it being made clear that R&D is not necessarily the only (or necessarily prime) variable of relevance. Battisti and Stoneman (2013), list the various innovation sourcing activities in their sample as engaging in R&D or design, and sourcing changes in business processes (process innovation), new equipment and software, or new branding and marketing methods. Table 2 shows the proportion of sample firms undertaking each type of sourcing by industry. Between one fifth and one half of firms have engaged in each of the different sourcing activities, with the sourcing of new software, and branding and marketing activity, most frequently observed. Only 21% of the sample reported having engaged in R&D activities indicating that the traditional emphasis upon R&D activity or expenditure as the sole or best indicator of sourcing activity could give a misleading picture of overall innovative activity.

{Table 2 about here}

There may also be significant complementarities across the different sourcing activities. The data indicates, for example, that of all firms that do R&D, 54% also do design and that of all firms that source new software, 35% also engage in new business processes.

IPFA identified just one factor which explains 54% of the overall sample heterogeneity. In this factor the weight on design is greatest; R&D and sourcing new business processes carry a slightly lower weight, with software and branding carrying the lowest weights. Three clusters of firms are identified (A, B and C) in the sample within each of which firms share similar patterns of sourcing (Table 3). This data clearly illustrates that the intensity of engagement in all activities steadily increases from cluster A to C, suggesting that few firms are very active in seeking new ideas, but when they do seek new ideas they do so on all fronts simultaneously. These findings reinforce the view that R&D is not necessarily the only (or necessarily prime) variable of relevance when discussing innovation.

{Table 3 about here}

5 International Diffusion

The international dimension of the diffusion process has been much less studied than diffusion within national boundaries. Although the growth and development literature has emphasised how technologies migrate from the north to the south and how important this can be to both economic development and the patterns of international trade (e.g. Grossman and Helpman, 1993), the diffusion literature per se has not expended much effort in looking at this international dimension. There is of course much literature that looks at the diffusion of different technologies in different individual countries, even comparatively[2], but there is little that takes an a priori international stance. Improved historical data on cross country technology diffusion (see, for example, Comin and Hobijn, 2003, 2009) has enabled much more work to be done in this field and there are many opportunities open. Pulkki-Brännström

[2] Comparative studies can pick up impacts that do not vary within but may vary across countries e.g. institutional factors such as patterns of taxation, degree of democratisation, extent of corruption, or the degree of political stability, but few of these have been much studied.

and Stoneman (2013) and Comin and Hobijn (2004) both talk of extensive and intensive margins in the international diffusion of new technologies. The extensive margin refers to the spreading of first use across countries while the intensive margin refers to the spreading of use within countries. The data clearly shows that even when the former is complete the latter continues.

Although little studied, taking an international standpoint immediately leads one to enquire whether cross country effects impact upon national diffusion patterns. Pulkki-Brännström and Stoneman (2013) explore possible effects via international information spreading and from firms operating on international markets. An international approach may also help to richen the story as to how supply side factors impact on the diffusion process. For example, it may be the case that, if, in a given country, the new technology being spread is imported with the supply side based overseas, then exchange rates may matter. The supply side may also be supplying a number of international markets which will enable cross-country feedback on supply side scale effects via learning by doing. In addition, in a given country, the incentives to and effects of the introduction of a new process technology in a firm may partially be derived from the overseas markets to which that firm exports. Moreover if a firm is exporting, or if a new technology is imported, the economic analysis of the welfare of different diffusion patterns may have to be conducted differently than under the autarky regime often assumed.

6. Supply side market structures

Often the industries that are the suppliers of new technologies experience patterns of evolution over time that suggest that it may not be particularly informative to represent such industries as in static competitive, oligopolistic or monopolistic states. I have tried in the past to label changes in the structure of the supplying industry as diffusion on the supply side. The point to be made here is that, if the supply side is evolving over time, then we need to know not only how and why, but also what impact this evolution will have on, for example, the quality and prices of the goods and services that embody the new technology because this will impact on the diffusion path. We know more on the former than the latter.

Consider a new technology that is embodied in a new original product and the first manufacture of which represents the birth of an industry. There is a substantial amount of existing literature that tells the story of what happens from here within several different disciplines. In Economics Sutton (1996), Geroski (1995), Gort and Klepper (1982), and Klepper and Graddy (1990) are relevant. This literature shows that for successful new products, after birth, competitors enter the market and start to sell comparable goods. Klepper and Graddy (1990) characterise industry development as having three stages. The dominant pattern is one where in the initial phase there is an increasing number of firms, in the second phase there is a decreasing number, and then in the third phase reasonable constancy. The lengths of these phases differ considerably across products.

An alternative but complimentary approach is that of Utterback and Abernathy (1975), see also Utterback (1994), who also identify three phases in industry development: the fluid, transitional and specific. In the fluid stage, early participants experiment with new forms and materials, there is no agreed or “dominant” design in the industry and firms test markets and technologies with many and varied new products placed on the market. Once a dominant design has been established this fluid stage with its intense rate of product innovation is over. In the transitional phase process innovation becomes the major innovative activity. In the final specific stage the rate of both major product and process innovations declines, with industries becoming mainly focused on efficient production and cost minimisation, with standardized, undifferentiated products. In different industries the phases may take (considerably) different periods of time.

Such patterns of industry evolution will be reflected in the rate at which new-to-market products (and thus improved or different processes for firms) are developed, the pricing of these products over time, the time patterns of expectations of improvement and obsolescence, and the rate of the development of standards and designs. All of these will impact upon the inter-temporal demand for the new product and thus the diffusion process, but currently are rarely considered.

7. Inter firm and intra firm diffusion

Within countries the extensive and intensive margins of use are across and within firms (or households), labelled inter and intra firm (or household) diffusion. The inter firm diffusion of new technology has always attracted most of the attention in the literature, intra firm being the poor relation, despite the early work of Mansfield (1963). Although there have been recent contributions in this area (e.g. Battisti, Canepa and Stoneman, 2009, Battisti et. al, 2007, Battisti and Stoneman, 2003, Fuentelsaz, Gomez and Palomas, 2012, 2009, and Fuentelsaz, Gomez and Polo, 2003) there is still a lacunae of evidence on the actual patterns of intra firm diffusion and their determinants and I believe that this area merits more exploration.

8 Firm performance and the diffusion on innovations

Much of the extensive body of work in Economics that explores the relationship between firm performance and innovation, has centred upon the relationship of performance (most often, total factor productivity) to R&D spending as a proxy for innovative activity (see, for example, the survey by Hulten, 2010). R&D may be a rather unsatisfactory proxy and it would definitely be preferable if performance could be related to the measured use of new technologies. Comin and Mestieri (2013) have undertaken some welcome work in which international macro level TFP differences are related to the diffusion of new technologies. However the relationship between the use and or diffusion of new technologies and firm performance at the micro level has been less studied.

There is some work that relates to technology adoption and firm performance. For example Bloom and Van Reenen (2007) relate firm sales growth to the use of new managerial technologies, and Geroski, Machin and Van Reenen (1993) relate profitability to innovative performance. However very little of this work takes a diffusion based point of view. For example it would be informative to explore whether: early adopters do better or worse than late adopters: firms of certain characteristics (e.g. size) gain more from adoption than others; the gains of earlier adopters decline as more firms adopt; while others are adopting non adopting firms suffer deteriorating performance. Any such findings would also provide some foundations for the hypothesised impacts of technology adoption that underlie many of the theoretical approaches in Economics to the modelling of technology adoption. While we have empirical studies that test indirectly whether rank (i.e. differences in firm characteristics), stock (more users means later returns) or order effects (early adopters gain most) matter in determination of the hazard of adoption (e.g. Karshenas and Stoneman, 1993) we have very little that directly attempts to measure the returns to adoption per se. Two exceptions are Stoneman and Kwon (1996, 1995) the former looking at profitability and the latter at productivity.

9. Diffusion Policy

It is disappointing that the vast majority of the political and academic comment on diffusion policy begins from the point of view that fast is good and faster is better. Much commentary relies upon simple international comparisons of adoption across countries where lagging behind is considered sub optimal. Even this simple representation has problems for a diffusion curve has three parameters, thus differences in usage at any point in time may be the result of different start dates, different asymptotes and/or different slopes and a snapshot of usage at a point in time cannot isolate which is important, and, for that matter, may not necessarily reflect relative usage at a different date.

Diffusion policy, like the majority of other policy analysis in Economics, should be based upon solid foundations (for support see David and Stoneman, 1986, and Ireland and Stoneman, 1986). Although there are several views as to what these foundations should be, my own preference is that they should involve defining the welfare optimal diffusion path and then discussing why the economy might deviate from this path. If one does so then one may argue that, for example, early policy stimulation of use may: lead to lock in to lower quality technologies that delays later transfers to higher quality; cause excess costs to be incurred by adopters because new technologies get cheaper over time; may encourage the inappropriate extension of new technologies to users for whom they may not be of benefit. Such observations previously seem to have had little impact on current policy discussion and more work is needed in this area.

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Table 1. Percentage of sample firms undertaking various innovative activities by sector.

Sector (SIC) ***sample size***	**New product /service**	**New business process**	**New strategy**	**New management techniques**	**New organisational structure**	**New marketing methods**
Accountancy (74.12) ***192***	31	21	18	17	18	33
Architectural services (74.2) ***217***	48	39	28	28	39	40
Automotive (34.3) ***61***	66	48	28	23	32	40
Construction (45) ***194***	25	23	27	29	31	37
Consultancy services (74.14) ***190***	54	38	45	34	48	55
Energy production (23.2, 40.1, 40.2) ***91***	47	36	33	31	36	40
Legal services (74.11) ***178***	37	32	28	30	33	46
Software and IT services (72.2 – 72.4) ***189***	70	41	43	34	47	54
Specialist design (74.87/2) ***185***	50	40	31	20	36	54
All (1497)	47	34	31	27	36	45

Source: Battisti and Stoneman (2013).

Table 2. Percentage of sample firms sourcing innovation by activity, by sector.

Sector	R&D	Design	Business processes	Software	Branding
Accountancy	6	22	21	57	46
Architectural services	30	35	39	58	46
Automotive	20	39	48	41	40
Construction	16	21	23	38	51
Consultancy services	24	46	38	50	56
Energy production	34	32	36	41	52
Legal services	10	25	32	42	60
Software and IT services	38	51	41	55	50
Specialist design	18	32	40	63	60
All	21	33	34	51	

Source: Battisti and Stoneman (2013).

Table 3. Percentage of sample firms sourcing innovation by activity and cluster,.

Cluster	**Sample size**	**R&D**	**Design**	**Change to business processes**	**New equipment and software**	**Branding and marketing**
A	625	3	5	6	21	24
B	562	23	42	43	69	67
C	220	68	92	90	90	90

Source: Battisti and Stoneman (2013).