REVIEW ARTICLES

The Economics of Technological Change: A Literature Review with Particular Reference to the Diffusion of Textile Process Innovations*

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1 Introduction
As pointed out recently by Soete1 (1985), technological change

"... has been the central factor in the industrial development of most advanced industrial nations, not only technical change in its most narrow form – the rate of advance of industrial knowledge – but also and primarily the broader concept of technological change including the actual diffusion of existing technologies."

Against this background this paper is concerned with the study of technological change and, in particular, its influence on the adoption of new technology in the textile industry. A brief survey of the literature on the economics of technological change is presented. This is designed to establish a satisfactory recognition of the concepts used in the analysis of technological change and to review some of the more important empirical studies. A summary of previous work based on the textile industry is included.

2 The Origin of Interest in Technological Change
It was through the study of economic growth that the importance of technological change, as the determinant of the structure, evolution and economic performance of industries, was recognized. One of the earliest contributions was made by Schmookler2 who, in 1952, forwarded the belief that the growth in the national product of the United States, in the 70-year period leading up to 1938, was due not only to the growth in the stock of capital and labour, but also to the growth of efficiency in the use of these resources. Similar conclusions were forwarded by Abramovitz3 in 1956, followed by Solow4 in 1957, Kendrick5 in 1961, and Massel6 in 1962. The factors other than the stock of capital and labour, which were believed to contribute to growth, were quickly dubbed the "residual". This residual was thought to be due almost entirely to technological change.

More recent research, however, has weakened the conclusions of these previous writers. For example, one prominent but admittedly controversial paper by Jorgenson and Griliches7 (1965) concluded that almost all of the observed total economic growth in the United States between 1945 and 1965 could be accounted for in terms of identifiable changes in quantities and qualities of inputs (both labour and capital) and by economies of scale. It may be commented, however, that these changes may in part be organizational, but could in addition embrace a technological component.

The response of economists to the results mentioned has been quite prolific, and although no definite conclusion has, as yet, been reached on the precise contribution of technological change to economic growth, it can at least be assumed that it has a prevailing influence. It was on the acceptance of this assumption that technological change itself moved from the fringe of economic analysis to take up a more central role.

3 Technological Change and the Production Function
In order to transpose the view of technological change into a more acceptable economic framework, it is necessary to introduce the concept of the production function. The approach followed draws much from that of Salter8 (1966) and Mansfield9 (1969), both of whom adopted the neoclassical perspective of technical change as involving shifts in the production function. As stressed by Blaug10 (1963):

"The case for the neo-classical approach is that it provides a meaningful framework for organising our knowledge of technical progress, and, to provide a more decisive consideration, no satisfactory alternative is in view."

The manufacture of a particular finished product from a raw material is achieved by using various
combinations of capital and other factors of production. For a given output of a particular product, a range of factor combinations is often available. Each combination is capable of producing the given output or less. The relationship between that output and the combination of factors capable of achieving it can be expressed as a production function. A production function, therefore, may be considered as specifying the relationship between inputs and a particular output.

It is the view of many investigators that the application of new technology within a firm may lead to a change in the production function which is specific to the stage of processing to which the new technology has immediate relevance. Salter, for example, pointed out that the appearance of new technology may:

"... lead to a new production function which is superior to its predecessor, in the sense that less of one or more factors of production is required to produce a given output, the input of other factors remaining unchanged."

A graphical illustration of a series of production functions would involve taking a given output and, in the simple but useful case where only labour and capital are under consideration, constructing alternative labour and capital requirements which could result in the production of the given output at the different times under consideration. Salter commented that the diagram which results is:

"... similar to the familiar series of iso-product curves of production theory, but time instead of output would be measured on the third axis and each curve would refer to the same output. Variations in output could only be introduced with a fourth dimension. However, if there are no economies or diseconomies of scale over the range of capacity outputs under consideration, the characteristics of the production function at each data are implicit in the curve for one output and labour and capital requirements per unit of output are unaffected by changes in output."

If the assumptions outlined by Salter are accepted, it seems feasible to construct Fig. 1 which relates a series of production functions directly to labour and capital productivity. Salter comments:

"These curves may run into each other but will not cross unless we consider special cases such as the retrogression of knowledge, the exhaustion of natural resources, or the imposition of legal or trade union restrictions for safety or other reasons. Apart from such cases, successive curves move inward towards the origin, reflecting the way in which new technical knowledge opens up successive ranges of alternative techniques which make possible new levels of productivity."

It should be noted that occurring parallel to the introduction of new technology are changing relative factor prices. Fig. 1 shows that the technique represented by point C is preferable to the techniques represented by points B and A, since less of each factor is needed to yield the given output. However, as the relative prices of input factors vary, it may be necessary to substitute capital for labour or vice versa. Thus C1 might represent a possible new combination of the factors of production, as also might C2, C3 or C4. Movement such as this, along an existing production function, constitutes factor substitution.

To elaborate further on the concept of technological change, it is necessary to discuss the role of innovation. Blaug (1963), in his discussion of innovation, pointed out that innovations are generally recognized as being either product or process innovations; but added that the distinction was to some extent an artificial one. He stressed that

"... the introduction of a cost reducing process is sometimes accompanied by a change in the product mix, while new products frequently require the development of new equipment. In practice, the two are usually so interwoven that any distinction between them is arbitrary."

As shown previously by Hann (1980), Blaug's statement holds true when examining the adoption of rayon fibre or yarn by Northern Ireland linen producers. This action seemed, at first, to refer only to the adoption of a product innovation by virtue of the characteristics of the resultant output. However, the decision to adopt rayon as a new raw material demanded a long series of changes in processing techniques. Nevertheless, as pointed out by Blaug, novel ways of making old goods can be distinguished, in principle, from old ways of making novelties.

Some researchers have viewed the process of innovation as extending into the productive process itself, believing that it was only through, and during, the application of a new technique that innovation
actually occurred. Norris and Vaizey\textsuperscript{16} (1972), for example, defined innovation as

"the embodiment of an invention in the productive process."

Norris and Vaizey also pointed out that it is difficult in practice to identify exactly the beginning and end of the innovation process. This outlook was supported by Usher\textsuperscript{17} (1929) when he suggested that "minor" or individual adjustments or changes continue to occur after an innovation has first been adopted. The importance of these additional changes was highlighted recently by Rothwell and Zegveld\textsuperscript{18} (1985) when they stated that,

"... radical and incremental innovations often will be closely linked, and a radical innovation will pave the way for an extended series of improvements, the sum total of which can have as marked an influence on the innovations commercial performance as did the original breakthrough."

This indeed seems to be the case, but it is necessary, for the sake of clarity, to consider subsequent developments of an innovation as different innovations entirely, although they may be regarded as within the same general category. An assumption of this nature can be accepted without difficulty, if the subsequent developments of an innovation are represented by different production functions.

The terms technological change and/or technological progress can be introduced to refer to the actual embodiment of an innovation within the productive process. Mansfield\textsuperscript{19} (1969) defines the term "technological change" as

"the advance of technology, such advances 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 or organisation, marketing and management."

Mansfield also commented that technological change reflects an advance in knowledge. Mansfield's definition embraces both product and process innovations, but does not make direct reference to the production function. A more precise definition was given by Miles\textsuperscript{20} (1968), who used the term technical progress to indicate the concept of,

"... absorption of scientific discoveries and technological developments into the actual productive process resulting in a reduction of the quantities of inputs per unit of output, and also, or alternatively, an improvement in the quality of output."

Miles' definition is broadly similar to that given by Hahn and Matthews\textsuperscript{21} (1964):

"In the simplest treatment, technical progress is regarded as something that goes on at an externally given rate and serves to bring about an increase, over time, in the output that can be produced by a combination of factors of production."

The definition given by Hahn and Matthews, unlike the previous two definitions, seems to be particularly oriented towards process innovations.

For the sake of clarity, it is suggested that:

(i) technological change be regarded as the embodiment of innovation in the productive process, and

(ii) technological progress be regarded as the result of that embodiment. In other words, technological change can be seen as a shift in the production function and technological progress the result of that shift in that the system of knowledge, known as technology, has advanced.

4 The Diffusion of Process Innovations

Accepting that technological change has a pervading influence on economic growth, it seems evident that a fuller understanding of this growth can only be achieved through an examination of the rate at which one technique supersedes another at the level of both the firm and the industry. Central to this fuller understanding are the questions:

How does the use of a new technique spread within a firm or industry and what will determine the rate of adoption of new techniques?

The importance of these questions has long been recognized, but it is only during the last thirty years that empirical studies have been carried out to answer them. The empirical studies have been hampered by the difficulty in obtaining company data, with the further impediment that results must usually be published in such a way that details of individual companies are not disclosed.

Before reviewing the relevant literature, it must be pointed out that the process whereby older techniques are replaced by newer techniques is now universally known as the diffusion process. Parker\textsuperscript{22} (1974), for example, viewed the diffusion of an innovation as a process.

"... by which the use of an innovation spreads and grows. Imitation and emulation are equal synonyms for the activity which broadens usage from source. In a simplified and highly schematic description of the process of technical advance, diffusion comes after invention and innovation, and is the stage where economic impact really begins to be felt."

In the past, when making empirical examination of the diffusion process, many researchers have made reference to two stages in the diffusion process, namely inter-firm diffusion and intra-firm diffusion. Smith\textsuperscript{23} (1974), for example, in his study of the diffusion of shuttleless looms recognized the two stages of the diffusion process

"... as diffusion from firm to firm (inter-firm or primary), and diffusion within firms (intra-firm or internal)."

Similarly, Mansfield\textsuperscript{24} (1969) differentiated, when he viewed inter-firm diffusion as

"... the rate at which firms begin to use new techniques," and intra-firm diffusion as
"... the rate at which a firm once it has begun to use a new technique continues to substitute it for older methods."

If adoption increases within firms, intra-firm diffusion is deepening. Intra-firm diffusion can, therefore, be regarded as the process beyond, but not inclusive of, initial adoption by a firm or industry. Inter-firm diffusion constitutes the process whereby a firm first adopts an innovation. Overall diffusion refers to the total penetration within a firm or industry.

5 Examples of Empirical Studies

One of the earliest empirical studies of the diffusion process was carried out by Griliches (1957) who made an examination of the diffusion of hybrid corn. Hybrid corn resulted from the invention of a method which propagated the best corn for specific geographical areas. This study considered rates of adoption in different regions of the United States and was the first formal study of diffusion rates. The work represented a landmark in the study of diffusion, for it illustrated that the diffusion process could be explained as a response to economic forces, particularly profit expectations.

Since the publication of Griliches' results in 1957, the work of Mansfield stands out as one of the most important studies of diffusion rates. In many ways, Mansfield can be regarded as a pioneer in the study of diffusion, but his work is restricted to the United States context. Mansfield, in 1961, examined the rates of diffusion of twelve innovations in four industries. These industries were: coal, iron and steel, brewing and railways. The study centred on the following hypothesis:

"... that the probability of a firm introducing the new technique is an increasing function of the proportion of firms already using it, and the profitability of doing so, but a decreasing function of the size of the investment required."

Mansfield pointed out that the hypothesis, when confronted by the data from twelve innovations, stood up "surprisingly well". He commented, however, that inter-industry differences in the rate of "imitation" existed.

The most comprehensive European study of the diffusion of process innovations was undertaken by the National Institute of Economic and Social Research. Eight major process innovations were selected and attempts made to analyze their diffusion in Austria, Italy, Sweden, the United Kingdom, the United States and West Germany. It is interesting to note that a common theoretical and methodological approach to the assessment of diffusion of the chosen innovations was not possible. Nabseth commented that

"This was less a failure to agree on a standard analysis, than a question of difference in the techniques studied and in the empirical material available. Furthermore, it may very well be that a standardisation would, in fact, have hidden important explanatory factors in the diffusion of some processes."

Among the papers presented by the National Institute was a study carried out by Smith (1974). This study was concerned with the diffusion of shuttleless looms. The conclusions arrived were as follows:

(i) During the first ten years of their availability, a reluctance to install shuttleless looms was exhibited.
(ii) Diffusion of shuttleless looms, in the six countries under consideration, seemed to have been faster than average in West Germany and the United States, and slower than average in the United Kingdom and Italy. Smith commented that "The 'laggard' tendency in the United Kingdom and Italy is associated with a more heterogeneous weaving industry with a large proportion of small firms, as compared with the highly concentrated American and German industries containing many vertically integrated firms."

On examining the degree of integration of adopters and non-adopters, Smith found that where vertical integration existed, firms were more prone to adopt shuttleless looms than were non-integrated firms.

In cases where firms had foreign subsidiaries, the extent of adoption was higher than otherwise.

In 1959, Sutherland examined the diffusion of shortened processing arrangements among a sample of Lancashire spinning firms. He found that adoption was higher among vertically integrated firms than among horizontally integrated or single process firms.

It must be stressed, at this stage, that it is a misconception to believe that an innovation is immediately applicable to the manufacture of the full range of an industry's output. In addition to the question of technical applicability, the problem of "complementarity" must also be considered. This occurs when adoption of an innovation at one stage of production necessitates the adoption of a complementary innovation at a subsequent or previous stage within the processing sequence. Parker referred to the induced effects arising from the adoption of an innovation as the "technological multiplier". It seems reasonable to suggest that the existence of a "technological multiplier" may have been a factor explaining Sutherland's results, for horizontally organized spinning firms may have been dependent for sales on horizontally organized weaving firms which had not adopted the necessary complementary innovations. In this case, adoption of new spinning technology would have necessitated a search for additional customers for the "new" product. Such a problem would not necessarily arise in a vertically integrated concern.
Metcalfe\textsuperscript{32}, in his study “Diffusion of Innovation in the Lancashire Textile Industry” (1970), made an analysis of the diffusion of three innovations aimed at improving sizing efficiency. The innovations were: (i) the electrical hygrometer, (ii) the accelerated drying hood, and (iii) the automatic size box.

Metcalfe’s analysis showed that, at the time of his study, the progress in the diffusion of innovations (i) and (ii) was further advanced than the diffusion of innovation (iii). It was noted, however, that innovations (i) and (ii) were available during the post-war boom, whereas innovation (iii) was not marketed until 1951 and was thus not available until a period of virtually continuous contraction in the weaving sector.

In addition, Metcalfe pointed out that innovations (i) and (ii) were of low capital cost with a short pay-back period, and that innovation (iii) was of high capital cost with a lengthy pay-back period. Innovations (i) and (ii) were viewed as simple additions to existing machinery, whereas innovation (iii) was more radical in nature and involved the replacement of units of machinery.

On examining characteristics of adopting firms, Metcalfe found that levels of diffusion tended to increase as firm size increased. This was most marked in the case of the automatic size box. In addition, Metcalfe showed that single-process firms had adopted the innovations to a proportionately smaller degree than multi-process firms.

Metcalfe also examined mortality rates among adopting and non-adopting firms. He concluded that adopters of the three innovations survived the industry’s decline better than non-adopters.

In 1984, Ray\textsuperscript{33} presented a follow-up study to that undertaken ten years previously for the National Institute of Economic and Social Research. The primary objective of this second study was to measure the extent to which six of the original eight process innovations had diffused further during the intervening ten years. Commenting on the favourable general acceptance of shuttleless looms, Ray stressed that the share of shuttleless looms in total shipments to developed economies was in many cases over 90\% and in some cases nearly 100\%. However in terms of proportion of total number of looms installed, Ray\textsuperscript{34} stated that shuttleless looms still had extensive scope for further application since, “... given the very long life of looms of the earlier types, the share of the new machines in the total loom stock of most countries’ cotton weaving industry is relatively small.”

In conclusion Ray commented that the future rate of replacement of existing looms by shuttleless looms will depend to a large extent on any future geographical shifts in textile processing away from developed economies. He went further to suggest that the labour-saving characteristics of shuttleless looms are of little or no significance, at least for the time being, in countries such as India where three-quarters of the looms are non-automatic.

6 Determinants of the Rate of Diffusion

It seems that the adoption (or non-adoption) of an innovation is governed not only by the characteristics of the innovation, but also the characteristics of potential users. Some of the factors identified by researchers are discussed briefly below.

6.1 Technical Suitability

It can be seen that certain innovations may not be technically suitable for application to the complete range of a firm or industry’s production. As diffusion of an innovation progresses, and re-development occurs, the technical performance of the machine improves and the product range to which the innovation is applicable may be extended further. This was recognized by Soete\textsuperscript{1}, for example, when he stated that, “As diffusion proceeds, and the specific user demands become more stringent, it can be expected that the effective use of scientific knowledge in improving the performance, quality and reliability of the innovation will increase substantially.”

In the follow up study of shuttleless looms, Ray\textsuperscript{35} commented that significant developments had occurred since the preliminary study, mainly with respect to “... higher speed, improved performance, better servicing and further noise reduction.”

In addition, he stressed that the range of products for which shuttleless looms were applicable had extended significantly.

6.2 Profitability

It is often believed that the profitability which may result from the adoption of a particular innovation within a particular firm has an important influence on the diffusion rate. As a general conclusion of their research, Nabseth and Ray\textsuperscript{36} not surprisingly pinpointed profitability as an important factor in explaining the nature of the diffusion process. This factor is seen not only to help in distinguishing between non-users and users, but also in explaining diffusion between firms and within firms. Profitability can be seen in the context of both the characteristics of the innovation and the characteristics of the adopter.

It is convenient to regard the profitability of an innovation in the context of the production function discussed previously. However, Nabseth and Ray\textsuperscript{37} point out that
"Since the capital market is imperfect, firms' opportunity costs differ. A high internal rate of return, for one firm, may very well be considered a rather low rate for another, at least in the short term, so that firms are likely to differ in their speed of application of a new process."

A major factor in the calculation of profitability is the relative price that one firm may have to pay for the factors of production in comparison with another firm. Nabseth and Ray\(^43\) referred to differences between firms and differences between countries. They point out that

"Numerically controlled machines and shuttleless looms which are, apart from their other advantages, very labour-saving, seem to have been adopted more rapidly in firms and countries with a relatively high wage level such as the United States and Sweden."

Mansfield\(^59\) also came to the conclusion that the profitability of an investment opportunity acted as a stimulus,

"..... the intensity of which seems to govern quite closely a firm's speed of response."

Another factor which is a characteristic of the innovation itself, as well as being linked to financial considerations, is the size of the capital investment necessary to adopt a particular innovation. A firm, faced with the decision to replace a certain machine, will not only compare the operating cost of the new technique to that of the old, but in addition, the amount necessary to yield a normal profit on its capital investment will also be taken into account. The higher the necessary investment, the greater the savings in operating costs must be to justify investment in a new technique.

Directing attention to the profitability of innovation, Metcalfe\(^40\) (1982) made the interesting observation that much of the emphasis in diffusion research is upon the profitability of using an innovation as seen by potential adopters, but less emphasis is placed on profitability as seen from the viewpoint of the producers of the innovation. He suggested further that much research into innovation ignores the supply side and with it the question how the profitability of adopting and producing the innovation is determined. He clarified his views by stating,

"Profitability influences the pace of diffusion but equally the pace of diffusion will influence profitability."

6.3 The Firm's Size and Structure

Larger firms might be expected to adopt an innovation more quickly than their smaller counterparts, since they are more likely to have access to adequate funds. Smaller firms are, it seems in a less favourable position to take the risk involved in being one of the first to adopt an innovation. However, Mansfield\(^41\) made the interesting discovery that small firms, once a beginning had been made,

"..... were quicker than large rivals to substitute the newer technique for the old."

Whilst not denying that large firms have certain advantages especially in terms of access to investment capital, Ray\(^52\) observed that

"..... after the initial phases of the innovation, once the new technology has matured and is receiving growing acceptance company size appears gradually to lose its significance."

The degree of integration of the firm can also be considered. As mentioned previously, research carried out by Sutherland, Smith and Metcalfe suggested that vertical integration was a factor contributing to adoption.

6.4 Other Factors

Such factors as management attitudes; labour market conditions, particularly the availability of certain skills; resistance of workers to change; access to information; and research and development activity are but a few of the possible additional factors affecting the rate of diffusion.

7 Summary and Conclusions

It was on the acceptance of the assumption that technological change was of far-reaching importance in economic growth that the former came to occupy a more central position in economic analysis. The production function serves to transpose the view of technological change into an orthodox economic setting. The process whereby older techniques are replaced through the application of new technology is known, universally, as the diffusion process. Inter-firm diffusion can be viewed in terms of firms adopting a certain technique for the first time. Intra-firm diffusion, on the other hand, is the process beyond, but not inclusive of, initial adoption. Brief attention was given to those factors considered by previous investigators to have some influence on decisions to adopt or not to adopt innovations.

Gold\(^43\) (1981), on examining some of the studies published during the 1960's and 1970's, noted that:

"..... The most valuable contributions made so far have been to reveal the need for more penetrating concepts, better measures, more comprehensive analytical frameworks, and wider samplings of the variegated phenomena to be encompassed."

In addition, he stated that the shortcomings of the literature tend to:

"..... mislead government officials and scholars concerning the depth and accuracy of our understanding of the causes and effects of differences among, and changes in, observed diffusion patterns."

Although significant contributions to the vast range of diffusion literature have been made recently by Davies\(^34\) (1979), Brown\(^45\) (1981), Metcalfe\(^40\) (1982),
Stoneman (1980, 1981) and Soete and Turner (1984), the validity of Gold’s criticism seems in general to have remained unchallenged. This seems to be particularly true in the context of the world’s textile industries. Clearly, there is immense scope, and a definite need for further research if understanding is to be enhanced.

References

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