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TECHNOLOGICAL DIFFUSION AND THE FINANCIAL ENVIRONMENT

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Abstract: This paper considers reasons why financial factors may impact upon the diffusion of new technology and potential means of furthering research upon this topic. The main aim of this paper is to undertake some preliminary discussion of how and why financial factors may impinge upon the diffusion process. Given that there is a close relation between the analysis of diffusion and the analyses of investment and R&D we proceed by first exploring the arguments that have been presented as to why financial factors may play a role in the determination of these. We then discuss the parallels with diffusion. This leads to some conclusions as to how the financial environment within which firms operate may impact upon the diffusion process. In a final section we discuss how this issue may be further researched.

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1. INTRODUCTION

The economic analysis of technological diffusion is primarily concerned with understanding the process by which new product and process technologies spread across their potential markets over time. The study of diffusion originates in the work of Schumpeter but modern theoretical analysis basically starts with the epidemic learning models of Griliches (1957) and Mansfield (1968), progresses with regard to process innovations through the probit or rank models of David (1969) and Davies (1979) through to the stock and order or game theoretic models of Reinganum (1981) and Fudenberg and Tirole (1985), with similar developments on the product innovations side. Alongside the theoretical developments there is a much larger empirical literature, not all of which is closely tied to the theories, but which has explored in some depth both the revealed patterns of the diffusion of new technology and the apparent drivers of these patterns. Stoneman (2001) provides an extensive review of these literatures.

Despite the growth of the diffusion literature one factor that seems to have merited very little attention to date is the role of financial factors in the diffusion process, where financial factors may be taken to encompass all issues relating to the funding of those capital expenditures that are a part of the technological diffusion process. Although some empirical work (e.g. Mansfield, 1968) has introduced finance indicators as an explanatory variable in diffusion equations this is not common and even in such cases is not justified on any theoretical grounds. This may be a significant omission. It is also a curious omission, for the role of financial factors in two related fields i.e. R&D determination (see for example Goodacre and Tonks, 1985 and Santarelli, 1995) and investment in plant and equipment (see for example Hubbard, 1998) has been discussed quite extensively.

The main aim of this paper is to undertake some preliminary discussion of how and why financial factors may impinge upon the diffusion process. Given that there is a close relation between the analysis of diffusion and the analyses of investment and R&D we proceed by first exploring the arguments that have been presented as to why financial factors may play a role in the determination of these. We then discuss the parallels with diffusion. This leads to some conclusions as to how the financial environment within which firms operate may impact upon the diffusion process. In a final section we discuss how this issue may be further researched.

2. INVESTMENT, R&D AND FINANCIAL FACTORS

Most analysis of the role of financial factors in the determination of investment or R&D spending starts with a restatement of the Modigliani and Miller (1958) theorem that if there are perfect capital markets then the firm's financial structure is irrelevant to its investment decisions and as such investment and finance decisions are independent of each other. In a perfect capital market therefore, financial factors would play no role in investment determination. This result however relies upon (at least) three basic assumptions holding i.e. that there are (i) no possibilities of default on loans (ii) no taxes (iv) no transaction costs. As such conditions do not hold generally, investment and finance decisions are interdependent and thus the nature and functioning of capital markets will impact upon investment undertaken.

Aspects of the nature and functioning of capital markets considered to be important in the investment and R&D literature then encompass:

(i) **Market completeness**. The completeness of a capital market concerns issues relating to the diversity of capital instruments available. Debt and equity are the two main capital instruments, but other instruments such as derivatives, venture capital and convertible bonds may also be available. Not only might some less developed markets not offer all such capital instruments but also it has been argued that even in the most sophisticated markets such as the UK and the US that there are "finance gaps" especially for small firms. The differences in the availability of venture capital in different countries are well documented. In certain cases e.g. for sales contingent finance contracts the gap may be such that only the government offers such a finance instrument. In fact Arrow (1962) identified the issue of missing markets for the shifting of risk as a key element leading to sub optimal R&D spending. If there are such gaps firms may well be constrained in the achievement of their optimal finance arrangements and their investment and or R&D spending may be affected.

(ii) **The number of buyers and sellers.** A perfectly functioning market requires a large number of buyers and sellers (large being defined to be sufficient to generate price taking as opposed to price setting behaviour). It may be that certain markets are very thin especially on the supply side and as such there are monopoly rents to be earned through higher finance charges. If so, then the higher costs of finance will either drive firms to use alternative, less suitable, financing and/or lead to less investment and or R&D.

(iii) **Market inefficiency**. Generally three levels of market efficiency are defined. Weak efficiency requires that market prices reflect all information contained in the record of past prices. Semi strong efficiency requires that prices reflect not only past prices but also all other published information. The strong form of efficiency requires that prices reflect not just public information but all information that can be obtained. If markets are inefficient then security prices will not correctly reflect available information and the cost and availability of finance may not be that appropriate to the investment or R&D project being funded.

If stock prices are not always strong form efficient then at some time the firm's stock will be undervalued. Myers and Majiluf (1984) argue that in such a situation firms may be reluctant to finance an investment through the issue of new stock since the new shareholders will benefit from the ultimate revision of the value of the existing stock. In such cases the management may pass over profitable projects. Further, as firms may be reluctant to issue new equity, they would use either fixed interest debt or carry financial slack in the form of retained earnings. This model forms the basis of Myers (1984) "Pecking Order" theory of finance in which firms rank sources of finance preferring to use internal funds first, then external debt and then finally new equity to finance new investments.

The evidence on market efficiency is mixed. Particular emphasis in recent years has been placed upon discussions of whether markets are too short termist and undervalue long-term investments. There is for example a growing body of literature on the market valuation of R&D see for example, Hall (1993). It is however difficult to draw conclusions on market efficiency on the basis of this literature. Very few authors now however regard markets as always strong form efficient (see for example Bond, 2000 for some recent estimates).

(iv) **Cost of capital.** When evaluating an investment project the correct discount rate for the firm to use in the calculation of the net present value of the project is the opportunity cost of capital appropriate to the class of investments. For standard projects that are simply extensions or replications of existing assets this may be obtained from the CAPM or arbitrage pricing theory. For example the discount rate relevant to project i derived from the CAPM is the risk free rate r_f plus a risk premium where the premium is equal to the systematic risk of the asset β_i and the excess return over the market return $(r_m - r_f)$ i.e.

$$r_i = r_f + \beta_i(r_m - r_f)$$

If the investment is of a sort that has not been undertaken elsewhere before then it may be particularly difficult to observe the systematic risk of similar projects in other firms (Goodacre and Tonks, 1995) and thus difficult to determine the appropriate discount rate. It may actually be that learning occurs as a project proceeds which leads to revisions in the appropriate rate.

Much investment, because it involves learning may in fact be better considered and valued as a real option. The valuation of real options is considered by amongst others Dixit and Pindyck (1994). However option-pricing formulae require a measure of the riskiness of the asset, which may not always be available. Neither is it clear that the market will apply the same option valuation techniques as the firm in the valuation of risky projects and this may cause problems in terms of financing. In particular although the firm may value the option of future investment possibilities, the market may either not value such or may not be sufficiently long termist to value them appropriately.

(v) **Asymmetric information**. In general the manager or firm undertaking an R&D or investment project will have far better knowledge of the costs of and payoffs to that project than the financier. This is asymmetric information. Goodacre and Tonks (1995) argue that because of the need for managers in such environments to provide signals to financiers as to the wiseness of their investment decisions, this may cause managers to undertake shorter term rather than longer term projects. In addition they argue that in the environment of asymmetric information the need of managers to signal their quality to financiers can lead to adverse selection against long-term projects. Nickell (1978 p.182) argues that asymmetric information will also tend to make the firm's cost of capital dependent upon recent levels of profitability. In particular he argues that the firm will face an upward sloping cost of capital schedule the height of which is inversely related to past profit flow and the steepness of which is inversely related to the availability of close substitute investments.

In the presence of information asymmetries (or incomplete information) recent work (e.g. Winker, 1999, p170) argues that credit rationing may appear. Credit rationing is taken here to mean that banks (and others) deny loans to borrowers who are observationally indistinguishable from those who do receive loans. In such circumstances it is the availability of capital and not its cost that determines the level of investment. Under credit rationing there will be some firms who are able to easily access external funds and such firms will be able to use such funds to smooth investment when internal funds fluctuate, but other firms will not easily be able to access such funds and for them investment will be conditioned by fluctuations in internally generated funds.

Even in the absence of credit rationing, asymmetric information may make external debt and equity more expensive that internally available funds.

(vi) **Moral hazard**. If an entrepreneur sells equity claims to outside investors then s/he is no longer the sole owner of the project and may be better thought of as the manager employed by the outside investor. In such principle agent relationships there is always a moral hazard problem in that the agent will always try to maximise his own utility rather than that of the principal. In particular it could be that this problem is especially exacerbated for long term decisions for the principal will then have to wait longer to see the outcome.

In such circumstances the literature has discussed many varieties of contracts that will encourage the agent to pursue the desires of the principals. Goodacre and Tonks (1995) illustrate how these may discourage longer-term investments. There is also some evidence that with optimal incentive contracts there may be under investment in risky projects by managers even when these are more attractive than a safe project.

(vii) **Corporate governance**. An alternative approach to the issue of the separation of ownership and control (principle agent issues) concerns the institutional arrangements relating to corporate governance. A commonly made distinction is that there is a much stronger market for corporate control in the US and the UK than Germany and Japan (Mayer, 1990), the former emphasising the role of takeovers as a market disciplining mechanism and the latter encouraging long-term relationships between investors (e.g. banks) and managers. The former however encourages liquidation of investment in the event of dissatisfaction with no obligation to take anything other than a short-term view. Such institutional mechanisms may well influence the extent and term of managerial investment decisions.

(viii) **Taxes and subsidies**. Financing decisions will logically be based upon after tax costs and returns. The tax environment will thus have considerable influence upon the extent of investment and the means of financing investment. As tax regimes may differ across countries one may expect to find inter country differences on preferred finance structures (e.g. the balance of debt and equity) and on after tax costs of capital as a result.

(ix) **Bankruptcy costs**. If there are bankruptcy costs then the Modigliani Miller theorem does not hold. In the context of R&D, bankruptcy costs may well arise from the inability of the owner of the R&D asset to receive a fair price for that asset in the event

of insolvency because the assets are highly specific and difficult to resell. Given that, with a risky project, cash flows are uncertain, it is possible that early in the life of such a project the profits will be insufficient to cover any interest payments on a debt instrument used to finance the project. For a newly established firm this could mean liquidation. Potential debt holders may well also realise this. For new firms or single project firms therefore equity may be the preferred borrowing instrument. For existing firms, the possibility of cross financing from other projects alleviates the bankruptcy risk and costs and thus there is not the same bias towards equity and debt and equity finance may be just as likely. There is some evidence to show that in the UK at least R&D intensive firms (i.e. those undertaking riskier activities) have a higher percentage of equity in their capital structure (lower debt equity ratio) than other firms (Goodacre and Tonks, 1995).

For all the reasons discussed above, one may expect to find that, to some degree at least, investment in plant and equipment or in R&D may well be affected by financial factors. For investment, this has been explored empirically in a number of papers by the inclusion of financial factors as explanatory variables in firm level investment equations, the most commonly used proxy for financial factors being a cash flow measure. Cash flow is used to indicate the extent to which the firm can rely upon internal as opposed to external finance and thus enjoy lower financing costs and less liability of being credit rationed. Schiantarelli (1996) and Hubbard (1998) present reviews of this literature. There is considerable evidence that financial factors usually proxied by cash flow do significantly impact upon firm investment. There is also some evidence that R&D spending is similarly affected. In fact R&D might be expected to be even more sensitive to financial factors than physical investments because it is relatively more risky and generates less easily realisable assets in the case of bankruptcy. However the evidence here is not particularly strong (Hall, 1992, Himmelberg and Petersen, 1994).

Some recent work has taken the analysis of the role of financial factors one step further. The arguments above would suggest that financial factors may play a greater role in investment and R&D determination is some institutional environments than others. A particular interest is in differences between Anglo American market based systems and German- Japanese bank based systems. Bond et al.(1997) find that the sensitivity of investment to financial variables is quantitatively more significant in the UK than in France, Germany or Belgium 1978 – 1989. This is interpreted as a particular failing of the market orientated UK system. Mulkay, Hall and Mairesse (2000) undertake a similar cross country comparison, but this time for both R&D and investment and between the US and France. Again significant differences are found across the

two countries with a greater importance of profit or cash flow as a determinant of investment in the US than in France, however any differences are much less obvious when it comes to R&D. Between 1982 – 1993, for investment, cash flow did not matter for French firms at all but significantly affected the investment of US firms. The authors argue that this is probably the result of real differences in the working of capital markets in the two countries. In particular they argue that US shareholders were somewhat more likely to sell their shares in adverse situations providing greater market discipline and thus more rapid responsiveness of US firms to changes in their prospects. To the extent that US firms feel pressure to use internal funds to finance future spending, they will have a higher long run response to surprises in profits (not accompanied by surprises in demands) than would otherwise be the case.

3. A CHARACTERISATION OF THE TECHNOLOGICAL DIFFUSION PROCESS

Investment in plant and machinery and the diffusion of new technology are in fact quite closely related areas of study. However whereas the former is concerned with analysis of changes in the stock of a capital aggregate the latter is concerned with particular capital goods and technologies rather than the aggregate. The concentration upon particular new technologies raises issues that may lead one to consider that financing problems for technological diffusion will be more severe than for investment in plant and machinery in the aggregate. There are also parallels between diffusion and R&D, in that R&D and diffusion decision making may be very similar and it may even be that diffusion involves R&D. Accepting this leads one to consider that financial factors may be as important in the diffusion process as in the R&D process.

The diffusion literature (see Stoneman, 2001) is concerned with the exploration of the spread of capital embodied innovations across households and firms (loosely labelled here product and process innovations) after first use has occurred somewhere within the economy. For both types of innovations, diffusion analysis is concerned with the intertemporal pattern of ownership of capital goods embodying the new technology taking account of intertemporal changes in demand and the creation of capacity to supply the demand. The empirical evidence suggests that the diffusion of new technology is a time intensive process. Often an S shaped curve when market penetration is plotted against time can represent the diffusion process. This suggests that diffusion starts slowly, then speeds up until some mid point after which diffusion slows but continues until some asymptotic level of penetration is reached.

Although financial factors may impinge upon households' decisions to acquire new product innovations, this is not the main issue here. Instead we concentrate upon

(i) the role of financial factors in firms' decisions to invest in capital goods that incorporate new process technologies and

(ii) the role of financial factors in firms' decisions to invest in capacity to supply new product or process technologies that are being diffused.

Although not the only framework used for analysing diffusion phenomena we concentrate upon the firm as the appropriate level of analysis.

The diffusion of product innovations involves the launching of new products by firms and the adoption of those products by households. In the household sector there may be processes of intertemporal information spreading and learning proceeding. In addition the heterogeneity of

households may cause different households to buy at different times. Purchase decisions will be influenced by inter alia, prices, product quality, expectations of future prices and quality, marketing activity on the part of firms, product diversity, standards, compatibility and attitudes to risk One may consider that in the early stages of diffusion the market will exhibit greater uncertainty than at later stages as the new product becomes more familiar and also as issues of standards and compatibility are settled. On the supply side, firms launching a new product will have to create the capacity to supply the product, continue product and process development improving the product or creating new variants over time and /or reducing its cost of production, finance marketing and other expenditures and also face the possibility of new entrants producing similar or replacement products. There may well be learning by doing or by use in the production of the new product and in addition accumulation of goodwill as the diffusion proceeds.

The diffusion of process innovations will exhibit similar characteristics. Existing firms buying new technology will need to decide upon when to initiate use of the new process and how quickly to transfer production from old to new technology (thus encompassing both inter and intra firm diffusion). For new firms, the use of new technology will be an entry decision. The firms acquiring the new technology may need to accumulate complimentary skills through work force training and there may again be learning by doing economies. There may also be issues of standards and compatibility. Decision making will take account of, inter alia, costs of acquisition, product quality and expected changes therein. In the early stages there may be considerable uncertainty as to the performance of the technology but as diffusion proceeds learning may reduce such uncertainty. There may be first mover advantages in the adoption of new process technologies. Early adopters may also have to finance search activity. Introducing the new technology may involve adaptation costs and/or R&D to adapt the technology to individual requirements. The suppliers of the new process technologies will face similar issues to those firms undertaking product innovation, although the market is now firms rather than households.

This brief sketch of the particularities of the diffusion process enables us to list a number of characteristics of the diffusion process that might lead one to consider that financial issues will play an important role in the determination of the diffusion pattern

(i) **Uncertainty**. Given that diffusion is concerned with doing something new the extent of uncertainty attached to a diffusion process may be greater than that attached to replication of existing activities. For example Stoneman and Toivanen (2000) show that across countries, investment in robot technologies shows much greater volatility than investment in machine tools in general. This higher level of uncertainty may exacerbate for the diffusion of new products and processes any problems that exist in raising

finance for investment. It may also cause problems in determining the appropriate cost of capital in that for new projects it may be difficult to determine the systematic risk of similar projects as there are no similar projects (a problem that will be ameliorated as diffusion proceeds).

(ii) **Information asymmetries**. As diffusion is concerned by definition with new technologies it may well be that the suppliers and users of those technologies are much more aware of their true nature and characteristics than potential financiers. As seen above in such an environment there may be credit rationing and or difficulties for the firm in raising external finance. However as diffusion proceeds the new technologies may become much more standardised and the markets may be more easily able to acquire and assimilate information. Benchmarking across firms may also be easier. Thus as diffusion proceeds the importance of information asymmetries may well reduce.

(iii) **Firm specific assets.** The diffusion process will generate (and require funding to acquire) a number of assets that may well be intangible, and/or firm specific e.g. learning economies of various kinds, knowledge from search, and/or product goodwill. As argued above such assets may not be realisable in the event of bankruptcy and/or may not be appropriately valued by the market. Once again this may make raising external finance problematic especially for firms without other assets that may act as collateral (unless, and this is possible taking a creative destruction viewpoint, successful diffusion causes losses in the value of other assets). The constraint that this may impose may reduce as diffusion proceeds and learning and intangible assets decline in relative importance.

Taken together these factors suggest that finance may well play a role in the diffusion process. In particular firms may be credit rationed, or the cost of external finance may be high. In addition if finance is available it may be short rather than long term in nature. If only short-term finance is available (largely because the market requires signals of satisfactory performance before providing further finance) such a restriction could especially impact upon the path of intra firm diffusion.

4. TECHNOLOGICAL DIFFUSION: THE POTENTIAL IMPACT OF FINANCIAL FACTORS

On the basis of the arguments above we can rationalise that the diffusion of new technology will not be independent of financial factors. To detail more fully how financial factors and diffusion may be integrated it is useful to consider the issues through four different viewpoints, i.e. across firms, technologies, countries and time.

(i) **Across firms**. The arguments above would suggest that given the intangible nature of many of the assets generated in the diffusion process there may be problems raising external finance especially for small firms. Where there are other assets that may act as collateral, equity and debt finance may be more accessible. This would suggest that larger firms would find investment in new technologies easier to finance. In addition firms with track records may be able to more successfully signal their capabilities to the market and thus new firms may find financing new technologies more difficult. Of course, as well, firms with extensive internal finance sources may find financing easier. This suggests that large existing profitable firms will face fewer financial constraints than less profitable smaller or newer firms will face. As the diffusion proceeds and as the new technology becomes more familiar and information asymmetries become less, these problems may become less of a constraint upon firms. The obvious implication is that larger firms with strong internal cash flows will, *ceteres paribus*, be earlier adopters of new process technologies or suppliers of new product technologies than smaller or newer firms with less cash flow, the latter firms being later adopters. It would also be reasonable to argue that similar patterns would arise when the intra firm diffusion of new technologies is being discussed, given the potential short term bias in external finance, although a general proposition that intra firm diffusion would be slower for all firms than if there were no financing constraints would also seem to hold. It would also seem reasonable to argue that firms operating in more volatile markets would face greater problems financing their diffusion plans.

(ii) **Across technologies**. Some technologies are simple and some complex. Some are expensive other cheap. Some are very leading edge others less so. Some will involve greater uncertainty than others. Some technologies will involve more learning by doing and using than others and some will involve more intangible and or firm specific assets than others To the extent that technologies are complex, more advanced and/or

expensive, more uncertain and involve more firm specific assets so financing is more likely to be a problem. It is clear to see that across technologies, *ceteres paribus*, the importance of financial factors will vary.

(iii) **Across countries**. Although firms my not only raise finance in their country of domicile, it is useful for the purposes of argument to consider that domestic financial markets are the main source. Across countries one may find differences in both the completeness of financial markets, differences in tax regimes and differences in institutions. For example in the Eastern European economies financial markets may well be quite primitive in terms of the size and scope of equity markets and the variety of financial instruments available whereas French, German, Italian and UK markets may well exhibit a large number of buyers and sellers and also a wide range of financial products. The more complete is the market the greater will be the availability of external finance (at lower cost) most suited to the firm's needs and thus the less is diffusion likely to be hindered. As for institutions, we have argued above that where the market for corporate control is strongest so one is likely to find the greatest short-term bias. Where there are close relationships between lenders and borrowers so the problem of informational asymmetry is minimised and thus longer-term finance will be more easily available. This would suggest differences across countries both in terms of inter firm diffusion (the distribution of first dates of use of technology) and intra firm diffusion (the time profile of take up within the firm).

(iv) **Across time**. As time precedes so capital markets change. Immature markets mature and grow, and even developed markets may change in completeness and in terms of the financial instruments on offer. Thus in Eastern Europe for example financial markets have appeared and are growing in sophistication. In more developed markets one may observe the growth of markets for derivatives, venture capital, markets for the equity of younger and smaller firms, securitisation, and greater competition in banking. All such changes will affect the availability of external finance to firms in terms of amount, costs and characteristics. This will impact upon the diffusion process. Perhaps the most significant change could be the introduction of EMU, in that with a common currency, national distinctions in credit markets become blurred and the bigger markets may be more competitive and more available to firms whom previously could not access such markets.

5. TECHNOLOGICAL DIFFUSION AND FINANCIAL FACTORS: THE EVIDENCE

There is, as stated above, very little evidence directly relating to the role of financial factors in the diffusion of new technology. The empirical work on diffusion as surveyed in Stoneman (2001) indicates that there is clear evidence that larger firms are earlier adopters and smaller firms are later adopters, as the above arguments would suggest. Generally however this is attributed to scale economies rather than financial factors. Davies (1979) shows differences in the diffusion of simple and complex technologies. Stoneman and Toivanen (2000) show that uncertainty has an impact upon the diffusion process. None of these results however are explicitly seen as the result of financial factors. Mansfield (1968) explicitly incorporated a liquidity term in an empirical diffusion equation explaining the intra firm spread of diesel locomotives in US railroads (measured as the ratio of the firms current assets to liabilities) and found a positive and significant coefficient.

Differences in diffusion rates across countries are notoriously difficult to measure and to the best of our knowledge there has been no explicit testing of the impact of different financial regimes on diffusion experiences across countries. However Bosworth, Stoneman and Sinha (1996) explore the data in the first Community Innovation Survey (CIS). This survey covers the innovation experiences of firms in 13 countries (with sample sizes from 399 – 22788) and is probably the most comprehensive such survey to that date. Although the survey addresses product and process innovation rather than diffusion directly the results would appear to be relevant. Question 12 of that survey asks " If any of the list of difficulties hindered the realisation of innovations in your enterprise during 1990 – 1992 please indicate its relative importance to your innovative activities". Bosworth, Stoneman and Sinha (1996) tabulate the responses as below.

Table 1. Major Hindrances to Innovation,

Factor	Number of countries for which the factor appears as one of the three most Important
Innovation costs too high	11
Pay off period too long	9
Lack of appropriate finance	7.5
Excessive perceived risk	5.5

Source: Bosworth, Stoneman and Sinha (1996)

These results suggest that although the payoff to innovations is a major factor affecting innovative activity, financial constraints are also strongly evident as is the effect of risk, and thus the financial environment that conditions the possibilities of shifting of risk. These results indicate that financial factors may well play a major role in the diffusion process.

6. THE WAY AHEAD

There are four potentially fruitful approaches that will allow us to move forward on the issue of the role of financial factors in the diffusion of new technology.

(i) **Theoretical development**. Much of the discussion above has been general rather than specific. Explicit modelling will only generate specific results and testable hypotheses. A first step therefore is to develop a model of technological diffusion under uncertainty (a sine qua non of financial factors playing a role) that can illustrate how, to what extent and with what interactions financial factors may impinge on the diffusion process.

(ii) **The CIS survey**. The CIS survey is a good source of data on innovation in Europe. Although not suited to the estimation of econometric models the survey contains much data that will be indicative of the role of financial factors in the innovation process. Using hypotheses derived from the modelling it will be possible to explore the relative importance of financial factors across countries, industries, firm size and firm types (e.g. domestic versus non domestic firms). In addition with the later CIS2 and CIS3 surveys it will be possible to explore whether there have been significant changes over time.

(iii) **Stand alone surveys**. Although there is no consistent source for data on diffusion across countries and time, there have been a number of stand-alone diffusion surveys undertaken in different countries. There would be some advantage to collecting together the data from and results of these different surveys. On the basis of this data it will be possible to explore whether financial factors have been addressed and if so what role have they been seen to play in different countries.

(iv) **Econometric analysis**. Some of the stand-alone surveys may well contain information upon financial factors or can be supplemented from public sources to provide such information (for example the UK CURDS survey can be supplemented by publicly available data on the firms in the sample to cover variables such as cash flow and profitability). With such data it will be possible to undertake explicit econometric estimation of the predictions of the models discussed under (i) above.

7. CONCLUSIONS

The analysis of technological diffusion has largely ignored the possibility that firms may be constrained in the diffusion process by the availability and costs of finance and/or different financial instruments. Building upon the literature relating to investment, R&D and finance we have argued that this may be a significant omission. In fact the diffusion process may well involve considerable uncertainty, information asymmetries, new types of assets, intangible assets and firm specific assets to a degree greater than investment in general. If so this may mean that financial constraints are particularly significant in the diffusion process. We have also argued that these constraints may be of differing importance across countries with different capital markets and different institutions and may also have changed over time as financial markets mature and or develop. Given the paucity of work in this area there is a need for further research. Suggestions have been made to advance our knowledge through both theoretical modelling and through empirical analysis using existing data sets.

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