# PRODUCTIVITY, INNOVATION DIFFUSION AND PUBLIC POLICY

**BY**

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Biography

Professor Paul Stoneman is currently Emeritus Professor, formerly Research Professor, Warwick Business School, University of Warwick. One time Visiting Professor, Stanford University and Visiting Fellow, Nuffield College, Oxford. Former member, Competition Commission Appeals Tribunal. Research interest centre upon the economics of innovation and technical change, especially diffusion. Extensive list of publications in the field include: *The Microeconomics of Product Innovation,* Oxford University Press, 2018 (with Eleonora Bartoloni and Maurizio Baussola); *Soft Innovation: economics, product aesthetics, and the creative industries,* Oxford University Press, 2010; *The Economics of Technological Diffusion*, Basil Blackwell, 2002; *Innovation and Research Policies: An International Comparative Analysis,* (with P. Diederen et al), Edward Elgar, 1999; and *The Economic Analysis of Technology Policy,* Oxford University Press, 1987.

## 1 Introduction

There is considerable evidence to support the view that the major driver of growth in total factor productivity (and labour productivity) is innovation and technological change. Despite the possibility of adverse terms of trade effects, it also generally accepted that innovation will and does drive increases in economic welfare over time (Feldstein, 2019). Most such literature however concentrates upon R&D, whereas it must be accepted that it is not until the results of research activity are introduced in to the economy (as well as innovations sourced other than through R&D and also imported from overseas suppliers) that one might expect productivity, output and economic welfare to be impacted. The analysis of the spread of product and process innovations across their potential markets is the study of innovation diffusion.

There is dearth of literature that looks directly at how the diffusion of innovations impacts upon productivity and economic growth. Stoneman and Kwon (1995) is a rare example quantifying the impact of technology adoption on firm productivity (in this case for a sample of UK firms). Much of the extant literature involves studies that explore Robert Solow's observation that it is difficult to isolate the impact of computerisation upon productivity and growth (Acemoglu et al.,2014). Conclusions upon the overall impact of technology diffusion upon productivity and growth must thus largely rely upon considering R&D spend as a potential proxy measure for diffusion activity. Similarly, there is also little literature that addresses policy issues relating to diffusion.

The sections below address: empirical regularities observed in diffusion processes; drivers of diffusion; rationales for policy interventions in diffusion processes; potential policy instruments; and possible outcomes from intervention. There are two relatively recent comprehensive surveys of the economics literature on technological diffusion available, Comin and Mestieri (2014) and Stoneman and Battisti (2010), that enable minimisation of the extent of referencing here.

## 2. Empirical Regularities

Much literature upon diffusion concentrates upon the spread of new process technologies across firms although there is a similar and related literature that relates to the spreading of new consumer products across households. Significant findings from these literatures include the following.

(i) Not all innovations are widely adopted but those innovations that are take time, and often a considerable period of time, to fully spread across their potential markets. The measured time taken often depends upon how widely an innovation is defined, for example, whether it is mobile phones as a whole being considered or different generations of mobile phones, the diffusion of the former taking longer than the latter.

(ii) The spread of an innovation involves both extensive and intensive margins. Innovations diffuse across countries (the extensive margin) and within countries (the intensive margin). Within countries they diffuse across industries and households (extensive) and within industries and households (intensive). Diffusion across extensive margins is always completed before diffusion across intensive margins is complete.

(iii) Diffusion, at both extensive and intensive margins typically follows S shaped curves where, plotting ownership or use in time t as a proportion of final use (or population) against time, generates a curve which shows an initial period of slow but then increasing growth up to a point of inflexion after which the growth rate slows and the level of use approaches an asymptote. Such curves have at least three parameters which describe the start date, the asymptote, and the time taken to reach the asymptote.

(iv) The products that embody innovations, be they consumer goods or producer (capital) goods, typically improve in quality and or reduce in price as time proceeds. Thus, over time the (quality adjusted) cost of acquiring innovations will decline and their potential and actual markets extend. In addition, the (horizontal) variety of new products and processes will also tend to increase.

(v) Any diffusion pattern will be the result of the interaction between changing demand over time for the innovation and the behaviour and reactions of the industry supplying the innovation, be that industry domestic or overseas. It will largely be developments in the supply industry that determine changes in the capacity to produce and supply the innovation, how it is priced, and how its performance or quality develop. Over time as diffusion proceeds so the supply industry will itself change, with the number of suppliers going up or down, often with early increases in the number of suppliers later being offset by reductions as products standardise. Production may also shift around the globe, north-south movements often being observed.

(vi) Just as the supply industry changes over time so may the industries and households that provide the markets for innovations. In particular, an industry adopting new processes will experience entry, exit and changes in firm sizes. These changes may actually be endogenous to the diffusion process. Newly established firms may have an advantage when installing innovations in that they have no historic cost burdens to bear and, as they use the latest technologies, they drive the older firms from the market. Similarly, early adopters will tend to be more competitive that non adopters and drive them from the industry.

## 3. Drivers of diffusion

There are a number of theoretical approaches that have been offered as explanations of the diffusion process itself and the resulting patterns observed. These may apply at the level of the country, industry, firm or household. The dominant approaches encompass:

(i) Diffusion of innovations occurs as knowledge of the existence and or capabilities of an innovation develops over time. In particular, knowledge is generated by prior use and as use extends so further use is encouraged either because more potential buyers know of the innovation and/or increased familiarity with the technology reduces the risks associated with it, thereby encouraging more users and/or greater use by adopters. These approaches encompass epidemic effects.

(ii) The diffusion of innovations may be closely related to the development of networks that support an innovation and thereby encourage further use. Specifically: standards relating to the innovation are established which facilitate adoption (e.g. the establishment of VHS as a dominant standard in the video industry); labour markets and skills appropriate to the innovation will be established (e.g. current developments re AI capabilities); also markets for inputs relevant to the innovation will develop (e.g. the establishment of a network of charging points for electric cars). These approaches encompass network effects.

(iii) Other modelling argues that innovations are adopted at different times because adopters are different and obtain a different gross gain from adoption. Relevant factors for process innovations may encompass firm size, skill availability, access to finance etc. For households, relevant factors may include income, risk aversion or education. If potential buyers adopt when the gain from adoption is greater than the cost of adoption, at any moment in time some potential buyers will have innovated and others will not. Over time buyer characteristics may change, the cost of adoption may fall or the performance of the innovation may improve and as it does so the extent of adoption extends. A real options approach suggests that buyers will acquire at that date when it is **most** advantageous to do so. This brings expectations re the future costs of acquisition or performance of the innovation into the technology choice decision. These approaches encompass rank effects.

(iv) Game theoretic approaches (mainly applicable to firms and new process innovations rather than households) argue that as the firms in an industry adopt an innovation the production costs of the adopters fall and, as a result, they produce more output. This increased output reduces industry output price and the profits of non-adopters which, under reasonable assumptions, leads to reduced gains from further adoption, thereby, for a given acquisition cost, limiting the extent of diffusion. Further extensions of ownership require the cost of acquiring the new technology to fall (or, less often considered, the demand for the product to grow). These approaches encompass stock effects.

(v) A variation on the stock effect is that the benefits from adoption depend upon the order of adoption, with early users gaining access to scarce resources or being able to establish barriers to entry or their own preferred standards. In such a world, for any given acquisition cost, only adopters up to a certain point in the order can profitably introduce an innovation. After that, diffusion only proceeds as the cost of acquisition falls or order effect are ameliorated. These approaches encompass order effects.

(vi) Further refinement of the rank, stock and order effect approaches endogenise the cost of acquisition and technology enhancement thereby relating innovation diffusion to the market structure of the supplying industry and changes therein. It should be noted that the suppliers of innovations may be based overseas and not in the domestic economy.

Although there is little empirical work that compares the merit of the different approaches, Karshenas and Stoneman (1993) employing an encompassing model applied to data upon the diffusion of a number of new manufacturing technologies in the UK find empirical support for the view that all approaches have some relevance. One may conclude that diffusion is not exclusively about the spreading of knowledge from productive to unproductive firms.

## 4. Why intervene?

That governments should and do intervene in the economy in order to improve the innovative performance of firms is well accepted throughout the world. There are various justifications for these interventions and many different instruments employed. It is fair to say however that the primary target of such interventions is R&D spending, whereas interventions aimed at the diffusion process are much less widespread and less generously funded. Stoneman and Diederen (1994) provides a base line from which to start any discussion of rationales for intervention in the diffusion process.

(i) One justification for intervention in the innovation process in general is that there are certain aspects of the economy that are the main responsibility of government and to the extent that they are unsatisfactory, government should spend to improve them. This could, for example, apply to the supply of public goods (e.g. defence), the national innovation system (Carlsson et. al., 2002), education and training, competition policy, etc. To the extent that the diffusion of innovations is just as important, if not more important, than R&D in generating growth and productivity, similar arguments can be applied to support actions that stimulate the diffusion of new technology. As examples one might point to: the role of government in the establishments of appropriate (international) standards to facilitate diffusion e.g. for electric vehicle chargers; a requirement upon regulators to encourage and foster the supply and use of new technologies through appropriate pricing regulation e.g. prices for accessing competitors' fibre optics networks; and legislation encouraging or forbidding certain behaviour e.g. the sale of new petrol or diesel powered cars.

(ii) A second major rationale for government intervention is market failure. There is a considerable literature that argues that government support for R&D is necessary because of appropriability problems and/or because of incomplete markets for shifting risk, both of which could cause firms to underinvest in R&D. Both arguments may also apply to actions involved in the spread of new technology. For example, it is often argued that early users spread knowledge to other potential emulators. However, early users can not appropriate this social benefit and as such may under invest (from a social welfare point of view) in early use. Similarly, the riskiness of early adoption compared to later adoption is recognised in the literature. The absence of markets for shifting risk (perhaps exemplified by difficulties of raising finance for early adoption of new technology) may be seen as a market failure.

(iii) A third main rational employed to support intervention by policy makers in the innovation process is international comparison. Although not having the academic groundings of the previous two arguments, the power of international comparative rankings encouraging intervention cannot be ignored. Although international comparisons of R&D spend as a proportion of GDP provides a simple and effective number on which to build policy interventions to stimulate R&D spendings (governments invariably wish to be near the top of the rankings) there are no such simple indicators of international comparative diffusion performance. In general, detailed data on the diffusion of new technologies is not collected systematically by national governments and very few data sets that allow international comparisons (one notable exception, is data for the EU on the spread of e-commerce https://ec.europa.eu/eurostat/statistics-explained/index.php/E-commerce_statistics). Data often employed for international comparisons primarily involves single cross sections of usage/ownership of different technologies at a point in time. However, diffusion tends to follow S shaped curves, and a single cross section contains no information as to whether observed differences are the result of different start dates, asymptotes, or rates of growth. Similarly, without knowledge of the differences across countries in various factors such as industry structure, firm sizes, costs of capital, etc. such comparisons yield no insight into why diffusion rates differ.

(iv) A final rationalization for intervention is that innovation is good and so more must be better, translating in the diffusion example, as that faster diffusion must be better. This argument may not however be correct. We have observed that new technologies improve over time as diffusion proceeds and also that they become cheaper to acquire, presumably reflecting, to some degree at least, greater productivity in their production. If intervention brings acquisition dates forward then: (a) the economy will bear the cost of installing less efficiently produced innovations and; (b) early installation of less efficient technologies will reduce the future net benefit from later installing more efficient technologies, thereby slowing later diffusion and reducing later productivity and welfare.

## 5. Policy instruments

Besides the behaviour of governments in the pursuit of its own activities, and those of its regulators, policies aimed to impact upon the adoption behaviour of the economy can be classified in two general classes,) information provision and subsidy (David and Stoneman, 1986).

Information provision policies include outreach activities that have for decades been and still are being undertaken to promote the spread of new agricultural technologies including new seed varieties, the use of fertilisers, irrigation technologies etc. in developed and developing economies. They may in addition also encompass advertising campaigns promoting the use of new technologies and also demonstration projects, either within government itself or promoted by government, from which potential adopters may learn.

The suitability of such policies depends upon whether the intent is to impact upon the extensive or the intensive margin e.g. inter firm diffusion or intra firm diffusion. It is often argued that it is much more difficult to get economic actors to do something for the first time than to get them to do more of what they are already doing. Thus, one would not expect information provision policies to have much impact in stimulating more extensive intra firm diffusion, for existing users will have information and knowledge learned from their own previous experience. On the other hand, non-users may be more responsive to such policies.

A particular problem with policies that fund information provision is that they take place in a world where others in their absence would also undertake such activities. Thus, for example, capital good suppliers would advertise and promote the new technologies that they are offering to buyers. When the environment does not allow advertisers to fully reap the benefit of their advertising (primarily when capital good supply is competitive) they will undertake less promotion than is socially desirable, and so public involvement may be effective; in other situations, greater public promotion activity may well be offset by a reduction in advertising and promotion by the private sector.

The other class of policies is subsidy policies whereby the use of a particular new technology is subsidised for (perhaps a limited) period of time to encourage adoption. Policy can be directed at firms or households and may impact upon both extensive and intensive margins. It is expected that such policies in addition to directly stimulating use will also have information spreading spin offs. Examples include recent subsidies to the purchase of electric cars while past UK examples have included subsidies to computers in schools. Although such policies can be effective, it should be realised that, in their absence, suppliers of innovations will have priced those innovations to effectively maximise their profits. The subsidy may well lead to a change (increase) in the profit maximising price that they charge such that some of the subsidy goes to the suppliers and the effective net subsidy to the buyer is reduced. It should also be noted that expectation effects may also impact upon behaviour in that expectations of a subsidy at a later time may cause buyers to hold back whereas expectations of an end to the subsidy may bring acquisition forward.

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