Innovation and Diffusion - The Implications of an Integrated Approach

P. Stoneman
N.J.Ireland

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I. INTRODUCTION

In the literature on the Economics of Technological Change it has become almost a convention to analyse the generation of new technology (Research and Development, or invention and innovation, or patenting behaviour) and the diffusion of new technology, as separate components in an overall process. It is the purpose of this paper to argue that the generation and use of new technology are inextricably linked and that separate analysis should be considered at best as yielding only part of the answers to any problems in the economics of technological change.

Examples of such separate treatment include two recent contributions to the literature on technological change. In the R & D field, Dasgupta and Stiglitz (1980), look at the determinants of R & D spending, and assume that any new technology generated is immediately used or diffused. In the diffusion literature we may consider an earlier paper of our own, Stoneman and Ireland (1983) where the spread of new technology is discussed under the assumption that the technology is given independently of the expected or resulting diffusion path. In this paper we argue that there is a link between R & D spending and diffusion; that it is important to realise the existence of this link; and that once this link is formally integrated into our modelling we gain a number of new insights into both the determination of R & D and the diffusion path.

To illustrate our argument, before attempting the formal modelling, we can summarise the basic elements of our approach. We consider a technological advance that is embodied in a new product that may be either a consumer or producer good. There is a set of users across which differing characteristics lead to demand for the new good being derived as a function of its price trajectory and its technological characteristics. The new good is produced by a supplying industry and, given the costs of producing the new good and its technological characteristics, the interaction of supply and demand determine a time profile of prices for the new good and thus the profit earned by suppliers. The nature of this profit stream provides the incentive to R & D. By specifying the competitive game in R & D and the R & D production relationship one can proceed to find R & D spending, the costs of producing the new good and/or its technological characteristics. This closes the circle enabling one to consider as endogenously determined R & D, the extent of technological advance and/or the production cost of the new good, the market structure of the supplying industry, the time profile of prices for the new good and its diffusion path. Factors which remain as exogenous are the characteristics of the buyers, the basic technology underlying the R & D process and the competitive games in R & D and product supply. Comparative dynamics exercises are then also feasible, and further it is possible to draw some welfare implications from the analysis.

In Section II of this paper we develop a simple two period diffusion model whereby the time path of ownership of the technology is determined by the interaction and the characteristics of the users and the producing industry and the time profile of costs of production of the new good. We discuss the welfare optimal diffusion path and when it might be generated and also detail how the suppliers' profits, which represent the incentive to R & D, may be found and how they will be determined.

In Section III we investigate R & D expenditure on product and process innovation, assuming a fixed number of firms undertaking R & D and illustrate how diffusion and R & D are interlinked. In Section IV industry equilibria are considered with free entry and exit and some welfare propositions are put forward. Conclusions are drawn in Section V.

II. DIFFUSION

In order to highlight and concentrate upon the linkages between the separate stages of the technological change process we proceed by using a particularly simple two period diffusion model as opposed to a more complex multi-period model. We have analysed a model of the latter type in two earlier papers (Stoneman and Ireland (1983), Ireland and Stoneman (1984)) and it is clear that the additional insight generated from a multi-period analysis is not, in the present situation, sufficient to merit the increased complexity.

We assume that there are N potential users of a new technology each of whom can acquire the new technology by the purchase of one unit of a new good. This new good has a life of at least two periods. We rank the users in the order (from highest to lowest) of the benefit obtained from purchase of the new good by the index X, $X = 1 \ldots N$. The number and characteristics distribution of potential users are assumed sufficiently large and dense to enable X to be treated as a continuous variable. Given the assumption of only one unit purchased per user, the rank of the marginal buyer in time t, X_t, is equal to the stock of the new good acquired by users up to time t. We will state that the valuation by the user for the purchase of the X^{th} unit is $f(X)$ if purchased at the beginning of period 1, and just $g_2(X)$ if purchased at the beginning of period 2. We may note that we are assuming that for any given user, the benefits he obtains are independent of the number of other users. This may suggest that the model is most appropriate to the case of a consumer product innovation. However, we felt there is no harm in pursuing a wider interpretation of the model so that the product may also represent a process innovation, as long as the limitations in this latter case are realised. To introduce an "order effect" whereby the Xth users's benefit is dependent on the number of other users would considerably complicate an anlysis that we have deliberately tried to keep simple in order to illustrate the main argument.

We will let $g_1(X) = f(X) - g_2(X)$ be the opportunity cost for the X^{th} ranked buyer of delaying purchase until period 2. In essence therefore $g_1(X)$ represents the benefits from ownership arising in period 1 and $g_2(X)$ the benefits arising in period 2. We will assume that users act competitively in the market, and we further assume that (i) $g_t(X) > 0$, (ii) $g_t'(X) < 0$, and (iii) $Xg_t(X)$ has a positive first and negative second derivative $(t = 1,2)$. This final assumption is equivalent to the usual condition that marginal revenue curves are downward sloping. In a number of places in our analysis we will use an example based on linear valuation functions, i.e.

$$g_t(X) = a_t - b_t X \quad , \quad a_t, \ b_t > 0 \quad t = 1,2 \qquad (1)$$

which enables us to derive some particularly simple results.

For the larger part of this paper we will attribute to buyers of the technology perfect foresight on prices. We have investigated elsewhere (Ireland and Stoneman, 1984) variations on this assumption. The diffusion path of ownership of the new product will result from the interaction of the period valuation functions $(g_1(X),\ g_2(X))$, the assumption of perfect foresight and the behaviour of capital good suppliers.

On the demand side, suppose that the price of the new good in the second period is p_2. Then, providing some sales takes place in the second period, total market sales (the total extent of diffusion) under perfect foresight will be X_2 where X_2 solves

$$p_2 = g_2(X_2) \tag{2}$$

If p_2 is the price in period 2, buyers with perfect foresight will only purchase in period 1 up to a sales level, X_1, that solves

$$g_1(X_1) = f(X_1) - g_2(X_1) = p_1 - p_2 \tag{3}$$

where p_1 is the price of the new good in period 1. For X greater than X_1 it is worth delaying purchase until period 2.

Let the n identical suppliers of the homogeneous new good each have unit production costs of c_1 in period 1 and $c_2 < c_1$ in period 2. Then the net revenues of a typical supplier with sales $x_1 = \frac{X_1}{n}$ and $x_2 - x_1 = \frac{X_2 - X_1}{n}$ in periods 1 and 2 respectively are defined as

$$S = (p_1 - c_1)x_1 + (p_2 - c_2)(x_2 - x_1)$$

which using (2) and (3) yields

$$S = x_1 g_1(X_1) + x_2 g_2(X_2) - (c_1 - c_2)x_1 - c_2 x_2 \qquad (4)$$

Under Cournot-Nash conjectures that each supplier considers other suppliers' behaviour regarding sales level as independent of its own, maximisation of (4) yields

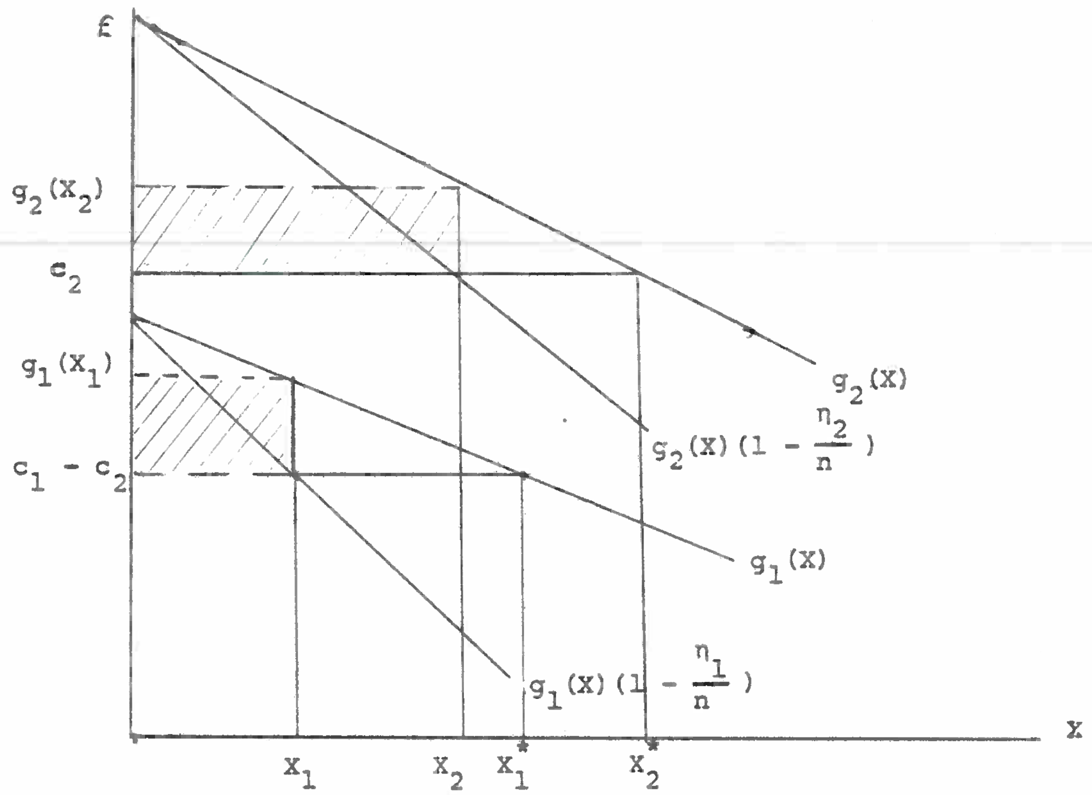
$$g_1(X_1)(1 - \eta_1(X_1)/n) = c_1 - c_2 \qquad (5)$$

$$g_2(X_2)(1 - \eta_2(X_2)/n) = c_2 \qquad (6)$$

where $\eta \equiv - g_t'(X_t) \left\{ \frac{X_t}{g_t(X_t)} \right\}$ i.e. the elasticity of the period valuation with respect to X.

In Figure 1 we show the equilibrium given by (5) and (6) when both period valuation functions are linear.

FIGURE 1



The shaded areas in Figure 1 sum to total (supply industry) net revenue.

For the linear case, we can also solve for each of the n symmetric supplying firms that

$$x_1 = X_1/n = (a_1 - c_1 + c_2)/\left\{b_1(1 + n)\right\} \tag{7}$$

$$x_2 = X_2/n = (a_2 - c_2)/\left\{b_2(1 + n)\right\} \tag{8}$$

and
$$S = \left\{b_1 x_1^2 + b_2 x_2^2\right\} \tag{9}$$

For the diffusion path to involve sales in both periods it is necessary that $x_2 > x_1 > 0$. This requires that, even with the perfect foresight assumed, some sales are made in period 2, and also that it is profitable to make sales in period 1. We assume that these conditions hold and thus that a diffusion process over time does in fact take place.

We should note however that the equilibrium solution for X_1 and X_2 given by (5) and (6) implies that diffusion is both slower and shallower than is welfare optimal.[1/] To show this, we may argue that a welfare optimal diffusion would imply that all customers are supplied in period 1 for whom the premium from having the product in period 1 is greater than or equal to the cost savings from delaying production until period 2, i.e.

$$g_1(X_1^*) = c_1 - c_2 \tag{10}$$

(where a star superscript refers to welfare optimality) and total sales of the product should be such that all who eventually buy at least value the product at c_2, i.e.

$$g_2(X_2^*) = c_2 \tag{11}$$

For the linear case, X_1^* and X_2^* are detailed in Figure 1. Either by inspection of Figure 1 or by comparison of (5) and (6) with (10) and (11) it is clear that X_1 and X_2 only approach X_1^* and X_2^* as n, the number of suppliers, becomes large, and in general $X_1 < X_1^*$, $X_2 < X_2^*$. Thus given perfect foresight, optimal diffusion will only be produced if the supplying industry is competitive.

In earlier work (Ireland and Stoneman, 1984), we have argued that if a monopoly supplier can perfectly discriminate charging a separate price to each buyer[2/] (a necessary condition for which was that buyers had myopic price expectations rather than perfect foresight), then the resulting diffusion path would be the same as the welfare optimal path. However under these conditions the monopoly supplier appropriates all the surplus as profits, whereas under perfect foresight with a large number of suppliers, although the diffusion path is welfare optimal the suppliers have zero surplus, the users obtaining the benefits. (To see this, if $X_1 = X_1^*$ and $X_2 = X_2^*$, the shaded areas in Figure 1 reduce to zero). Thus, although the same diffusion path may result from different expectations and structural assumptions, the distribution of the surplus will generally be very different. It is however precisely this surplus that is the incentive to the development of new technology, and thus one may expect such development to be sensitive to both the expectations regime of technology buyers and the structure of the supplying industry.

III. RESEARCH AND DEVELOPMENT

In the previous section we analysed the diffusion path of a technology of given characteristics illustrating the role of market structure and expectations in the determination of the surplus earned by the suppliers of the new product. It is this surplus that acts as the incentive to develop new technology and this is the link between the generation of new technology and its diffusion. In an attempt to obtain the surplus firms will undertake R & D, developing new technology in competition with other potential suppliers. This competitive process will determine the nature of the technology to be sold i.e. $g_1(X)$ and $g_2(X)$, if firms compete by "product innovation", or the production cost of the technology, i.e. c_1 and c_2 if they compete through "process innovation".

The problem with analysing product innovation is that if firms innovate at different rates one can no longer assume homogeneous products. We thus restrict ourselves to consideration of product innovation in a world of monopoly with no entry. Process innovation does not present such problems and thus we are able to consider other market forms.

Assume that each supplier of the new good undertakes his own Research and Development spending and that technological knowledge is not traded; also that each supplier is able to calculate the surplus he will obtain from any given technological advance and that he has knowledge of his R & D costs. Thus each supplier will have a known profit stream of the form

$$\Pi = S - R \tag{12}$$

where S is defined by (4) as the profit made from supplying the new product and R is expenditure on R & D.

Turn first to the consideration of a world where there is only one actual and potential new good supplier whose R & D expenditures are directed towards product innovation. In this context we consider that product innovation will involve changes in the valuation of the new good by its users. Specify two parameters Θ_1 and Θ_2 that enter respectively the functions previously written as $g_1(X)$, and $g_2(X)$ such that $\frac{\partial g_t}{\partial \Theta_t} > 0$ $t = 1,2$, i.e. a higher value for Θ_t increases the X^{th} ranked user's valuation of the new good in period t. We now consider that, to achieve product innovation, R & D expenditure is required according to the convex function

$$R = \phi(\Theta_1,\Theta_2), \quad \frac{\partial\phi}{\partial\Theta_t} > 0, \quad t = 1,2. \tag{13}$$

With a monopolist supplier $(n = 1)$, maximising profits Π, given (5), (6) and (13), Θ_1 and Θ_2 satisfy

$$\frac{\partial g_t(X_t,\Theta_t)}{\partial\Theta_t} \cdot X_t = \frac{\partial\phi}{\partial\Theta_t} \quad t = 1,2 \tag{14}$$

i.e. given Θ_1 the firm will spend on R & D improving the benefits from usage in the second period until the marginal cost of doing so equals its marginal profit from doing so. One can argue similarly with Θ_1. As should be clear the ratio of Θ_1 to Θ_2 is endogenous thus making the <u>intertemporal</u> distribution of the benefits from ownership endogenous. Given the endogeneity of Θ_1 and Θ_2, the equilibrium will thus be given by (5), (6), (13) and (14) with X_1, X_2, Θ_1, Θ_2 and R all jointly determined.

To illustrate what is to be gained from the linking of diffusion and R & D we will undertake an exercise in comparative dynamics. To simplify this exercise we assume that the $g_t(X)$ functions are linear. We may then identify $a_t \equiv \Theta_t$ implying $\frac{\partial g_t(X_t,\Theta_t)}{\partial\Theta_t} = 1$, $t = 1,2$. We will analyse the impact of a change in the unit cost of production of the new good in both periods 1 and 2 by an amount Δc. One may immediately observe from (7) and (9) that, in the absence of any change in Θ_t, given $n = 1$, that X_1 would remain unchanged and X_2

would fall by an amount equal to $\Delta c/2b_2$. Thus, if we ignore any reactions in R & D, the effect of an increase in the cost of production of the new capital good would be to reduce X_2 (the extent of diffusion) with X_1 (the speed of diffusion) remaining constant. The monopolist supplier's surplus S would also be smaller.

The question that now arises is how the R & D reactions will affect this result. From (14) it is clear that given $\partial g_t(X_t\Theta_t)\partial\Theta_t = 1$, $X_2 = \frac{\partial\phi}{\partial\Theta_2}$, and thus as X_2 declines, $\partial\phi/\partial\Theta$ must decline, and given ϕ is convex, $\frac{\partial^2\phi}{\partial\Theta_2^2} > 0$, and Θ_2 must decline. Given $\Theta_2 = a_2$, from (8) X_2 must suffer a further decline. Thus we have

<u>Proposition 1</u>

Given a monopolist supplier directing R & D towards product innovation, the dependency of R & D on the diffusion path implies that in reaction to an increase in the cost of producing the new product, the final level of use of the new technology, X_2, will be reduced further than if there were no such dependence.

The response of Θ_1 and thus X_1 to the decline in total sales X_2 is less clear. From (14) if $\frac{\partial^2\phi}{\partial\Theta_1\partial\Theta_2}$ is zero, then X_1 will remain unchanged. This is the case when ϕ is separable. If there is complementary production of innovation so $\frac{\partial^2\phi}{\partial\Theta_1\partial\Theta_2} < 0$, then X_1 will fall, whereas if $\frac{\partial^2\phi}{\partial\Theta_1\partial\Theta_2} > 0$, then X_1 will increase. Thus we have

Proposition 2

Given a monopolist supplier directing R & D towards product innovation, the dependency of R & D on the diffusion path implies that, in reaction to an increase in the cost of producing the new product, the speed of diffusion of the new technology, X_1, will increase or decrease depending on whether first and second period improvements are complementary or not in the R & D process.

When we consider process innovation our analysis can be made somewhat richer for we can consider an oligopoly supplying industry without the added complication of differentiated products. In the R & D cost function we can now consider $-\Theta_1$ and $-\Theta_2$ as the unit costs c_1 and c_2 in the two periods of the (typical) supplying firm. Then (c_1, c_2) that maximise Π given (5) and (6) satisfy

$$-x_1 = \frac{\partial\phi}{\partial c_1} \qquad (15)$$

$$-(x_2-x_1) = \frac{\partial\phi}{\partial c_2} \qquad (16)$$

and the equilibrium is determined by (5), (6), (13) (15) and (16). The impact of the R & D-diffusion link can be illustrated by considering the effect of a change in the number of suppliers n, each of whom, it is being assumed, undertake their own R & D. In the absence of any R & D reactions, our assumptions on the slope of the $g_t(X)$ functions and the equilibrium conditions (5) and (6) are sufficient to ensure that given c_1 and c_2, $\partial x_t/\partial n < 0$, $\frac{\partial X_t}{\partial n} > 0$, $t = 1,2$, $\partial(x_2-x_1)/\partial n < 0$ and $\partial(X_2-X_1)/\partial n < 0$ i.e. as the number of suppliers increase, the cumulative sales of an individual firm decrease but total industry cumulative sales increase at $t = 1,2$; however, second-period sales alone, both per firm and in total, decline. It will also be the case that as n increases, the surplus earned by each firm declines.

We now consider the reaction of process orientated R & D to these changes. Maintaining the assumption of Cournot-Nash behaviour, as n increases each firm has smaller cumulative sales and thus less incentive to undertake R & D. The effect of these lower incentives, from (15) and (16), will be that at least one of c_1 and c_2 will increase as a result. Exactly what happens to c_1 and c_2 will depend on the degree of complementarity in R & D. We might expect that with process innovation, the norm would be that if R & D expenditure reduced c_1, c_2 would simultaneously be reduced. This leads us to consider a particular case where innovations are perfectly complementary so that $dc_1 = dc_2 = dc$. We may note that in this case as $c_1 - c_2$ does not change, the R & D reaction to the change in n will have no further effect on X_1, for this is only dependent on the difference between c_1 and c_2 and not on their levels. In this case (15) and (16) are replaced by

$$-x_2 = \frac{d\phi}{dc} \tag{17}$$

Thus as the increase in n reduces x_2, $\frac{d\phi}{dc}$ must fall, c increase, and through (6), the increase in X_2 resulting from the increase in n must be partly or wholly counteracted by the R & D reaction. It is also clear that R & D spending per firm will be reduced. We may thus state

<u>Proposition 3</u>

Considering a Cournot-Nash equilibrium with suppliers directing R & D towards process innovation, the dependency of R & D on the diffusion path implies that in reaction to an increase in the number of suppliers, the final level of use of the new technology (given first and second period innovations are perfectly complementary in R & D) will be reduced below the level it would reach if there were no such dependence.

There is no a priori reason why the sum of the two effects, the direct competition effect and the indirect effect through R & D should be of any particular sign. Thus the net effect of an increase in n may be either an increase or decrease in X_2. The importance of this result is best illustrated by reference to the literature on patenting. This literature argues that there is a conflict between the granting of patents and the diffusion of new technology. Patents stimulate R & D by granting market power, but this market power limits diffusion. Our result, if we equate the severity of patent laws to the number of suppliers, suggests that there may not be such a conflict between patenting and diffusion for although there is a competitive effect limiting diffusion the extra R & D expenditure could sufficiently improve technology to overcome the competition effect. Thus tighter patent laws and extended diffusion could go together.

IV. INDUSTRY EQUILIBRIUM

In the last section the number of suppliers was treated as exogenous. However the work of Dasgupta and Stiglitz (1980) especially, has taught us to treat such an assumption with caution. Thus in this section we will consider the number of suppliers as endogenous. We consider two different views of equilibrium and then briefly contrast the equilibria with one which maximises welfare.

One approach to an industry equilibrium involving the determination of R & D is that used by Kamien and Schwartz (1982). Basically it concerns product innovation with inviolable patent rights where the firm willing to spend most on R & D gains sole rights to the new product and becomes the monopoly supplier. Competition for the role leads to zero profit and R & D may be carried to excess in order to secure the market rights. The marginal profit maximising conditions of the last section are replaced by

$$S = R \tag{18}$$

where S is maximised with respect to the diffusion path given one supplier. We have already argued that with one supplier, S is sensitive to the expectations of new technology buyers. This leads to an important observation arising from the R & D diffusion link that does not seem to have been made in the literature to date. Given that S is greater if buyers are myopic rather than having perfect foresight, R will also be higher under myopia. Higher R will produce greater technological advances reinforcing the impact on the speed and extent of diffusion generated by myopia. We may thus state

Proposition 4

In a "race to patent" framework, the extent of technological advance and R & D spending will be greater if buyers of the new technology are myopic than if they have perfect foresight during the diffusion process.

A second approach which develops from the previous section implies a supplying industry equilibrium with n symmetric firms, but with entry and exit of firms brought within the model. Each firm undertakes R & D to maximise profits but the number of firms undertaking R & D and thus supplying the new product will be such that the profits of all firms will be zero. To keep the model simple our attention will again be limited to process innovation and a homogeneous product. We will assume free entry and thus consider a Cournot-Nash zero profit equilibrium. For the typical firm given symmetry we have the zero profit condition (18). Assuming that process innovation is perfectly complementary ($dc_1 = dc_2 \equiv dc$), optimality in the amount of process innovation requires

$$\frac{dS}{dc} = \frac{d\phi}{dc} \qquad (19)$$

Confining our analysis to linear $g_t(X)$ functions, the equilibrium will[3] be described by (20) and (21) holding for each firm.

$$F(n,c;\ a_1,a_2,b_1,b_2) \equiv \frac{1}{(1+n)^2}\left[\frac{(a_1-c_1+c_2)^2}{b_1} + \frac{(a_2-c_2)^2}{b_2}\right] - R = 0 \qquad (20)$$

$$G(n,c;\ a_1,a_2,b_1,b_2) \equiv -\frac{(a_2-c_2)}{b_2(1+n)} - \frac{d\phi}{dc} = 0 \qquad (21)$$

We can consider $F(\cdot)$ and $G(\cdot)$ as jointly determining each firm's R & D expenditure (proxied by c) and the number of firms. Given n and c, the diffusion path is then given from (7) and (8).

Consider first the impact of changes in the $g_t(X)$ functions ($t = 1,2$) on the diffusion path given n and c both fixed. Then comparative statics using (7) and (8) with respect to a_t and b_t yield results which are given in Table 1.

TABLE 1 : Comparative Statics Results with n and c fixed

Effect on \ Change in	a_1	b_1	a_2	b_2
x_1	+	-	0	0
x_2	0	0	+	-
X_1	+	-	0	0
X_2	0	0	+	-

Now comparative statics of the full equilibrium incorporating R & D expenditure and the number of firms as endogenous is aided by assuming that the equilibrium is stable. A simple dynamic model then implies that the matrix

$$\begin{bmatrix} F_n & F_c \\ G_n & G_c \end{bmatrix}$$

and its inverse have two negative eigenvalues and thus a positive determinant i.e.

$$F_n G_c - F_c G_n > 0$$

Also

$$F_n = \frac{-2}{1+n} R < 0$$

$$F_c = \left(\frac{2}{(1+n)} - 1 \right) \frac{d\phi}{dc} \gtrless 0$$

$$G_n = \frac{-1}{1+n} \frac{d\phi}{dc} > 0$$

and
$$G_c = \left\{ \frac{1}{b_2(1+n)} - \frac{d^2\phi}{dc^2} \right\} < 0$$

which we obtain from the equilibrium conditions (20) and (21). Note that $G_c < 0$ is equivalent to $\frac{d^2\Pi}{dc^2} < 0$ (holding other firms R & D constant), and this is required to satisfy second order conditions. The marginal profitability of R & D must decline for stability if other firms' similar choices of R & D expenditure are taken into account. Given these signs, the comparative statics results shown in the following Table 2 can be derived.

TABLE 2 : Comparative Statics Results across Industry Equilibria

effect on \ change in	da_1	db_1	da_2	db_2
dR	−	+	+	−
dn	+	−	?	?

As Table 2 indicates, an outward shift in second period demand (da_2)

has "normal" effects on R & D. Whether the shift provokes entry or not depends upon the $\phi(c)$ function. As demand changes each firm increases R & D in order to gain more from its increased sales forecast, but as all firms do this (contrary to each individual firm's Cournot-Nash conjecture) the price is depressed and profitability may in fact be increased or decreased, occasioning either entry or exit. On the other hand, an outward shift in demand in the first period (da_1) produces a sufficiently large entry that output per firm decreases and there is less incentive to R & D.

These equilibria considered above suppose that the number of firms (n), the level of R & D per firm and the sales path per firm are all in equilibrium prior to any actual activity taking place, and no entry or exit will take place after activity begins and surpluses are made.

The results in Table 2 can be used to look at how our results in Table 1 have to be modified when the full equilibrium is considered. Obviously we can say nothing of the effect of changes in da_2 and db_2 on the diffusion path given that their effect on n is unsigned. The effect of changes in a_1 and b_1 on R and n is more definite. We have that an increase in a_1 leads to a decline in R, (thus c is higher), and an increase in n. From (8) it is clear that x_2 will be lower (holding a_2, b_2 constant), but we cannot sign the change in X_2. The effect on x_1 is not clear from (7); the increase in a_1 increases x_1 while the increase in n decreases x_1. However, also from (7), it is clear that $dX_1/da_1 > 0$.

Now consider a change in b_1. As $dR > 0$, c will be lower;

$dn < 0$. Thus from (8) $dx_2 > 0$, but the sign of dX_2 is not determined. Using (7), the sign of dx_1 is not determined, but $dX_1 < 0$. We may tabulate these results.

TABLE 3 : Comparative Statics results in the full equilibrium

effect on \ change in	a_1	b_1	a_2 or b_2
x_1	?	?	?
x_2	−	+	?
X_1	+	−	?
X_2	?	?	?

The extension of the model has invalidated almost all of the comparative statics results reported in Table 1. It is in fact the combination of endogenous R & D and free entry of firms which leads to the ambiguities in the results.[4/]

The particular point of interest in these results is that when governments attempt to speed diffusion, one of the policies used is to provide user subsidies i.e. changing a_1, b_1, a_2, b_2. As we can see from Table 3, the impact of such subsidies is extremely difficult to predict. We may summarise our results as:

Proposition 5

In a free entry zero profit industry equilibrium, the impact of changes in the parameters of the benefit functions has the expected effect on industry Research and Development, but the knock-on effects on the number of suppliers is not always signed. The impact on the diffusion path in most cases is of unknown sign.

Finally in this section, we will consider some implications of our analysis for welfare. As in similar kinds of analysis existing in monopolistic competition theory, two kinds of question can be asked. The <u>first-best</u> question relates to whether R & D expenditure is greater or less than the level which maximises welfare given accompanying welfare-optimising decisions concerning the diffusion path. The <u>second-best</u> question relates to whether R & D expenditure is greater or less than the level which maximises welfare given other decisions are fixed. In the case of the competition for monopoly rights approach considered first, the <u>second-best</u> question has a clear answer. There is over expenditure on R & D provided some positive profits could be attained at a lower level of R & D. This is demonstrated in Figure 2 where net surplus given perfect foresight is maximised at R^* whereas actual expenditure under the competition for monopoly rights approach is R^a. However comparison of R^a with that level of R which maximises net surplus Π' given myopic buyers and a perfectly discriminatory price trajectory (which we argued above yields the welfare optimum) is ambiguous, and thus the first-best welfare question is unresolved.

In the case of a zero profit free entry equilibrium with process innovation, the first point to note is that if $n > 1$, then R & D is being duplicated. In the sense that each firm is different and suffers from diseconomies of scale outside our model, this may be unavoidable but in our context it implies that we can only really consider the second-best question. Would we wish to subsidise, tax or otherwise regulate R & D expenditure in the supplying industry?

First, consider the case where there are a fixed number n of firms in the supplying industry. Then the total net welfare arising is the sum of consumers and producers' surplus:

$$W = \int_0^{X_1} (g_1(z) + g_2(z) - c_1)dz + \int_0^{X_2} (g_2(z) - c_2)dz - nR \quad (22)$$

If we restrict ourselves to the case of perfectly complementary process innovation with $dc_1 = dc_2 = dc$ then

$$\frac{dW}{dc} = \left[g_1(X_1) - (c_1 - c_2)\right] \frac{dX_1}{dc} + \left[g_2(X_2) - c_2\right] \frac{dX_2}{dc} \quad (23)$$
$$- X_1 - (X_2 - X_1) - n\frac{dR}{dc}$$

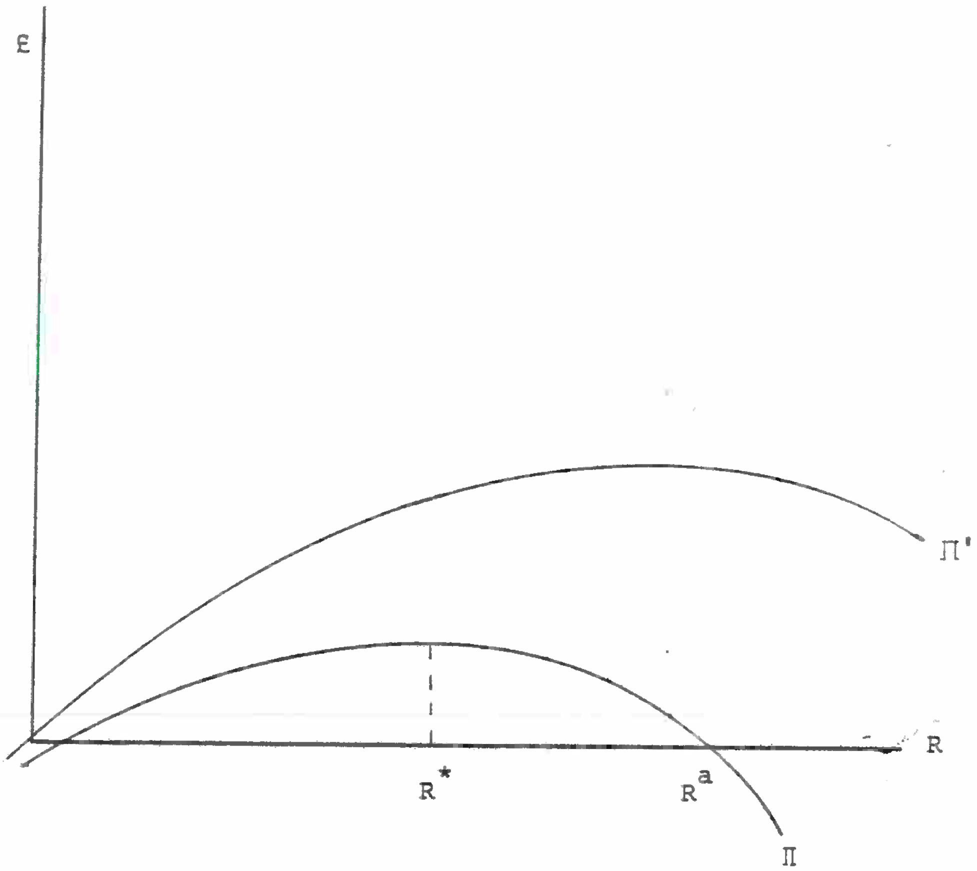


FIGURE 2

Perfect foresight of buyers, together with a Cournot-Nash equilibrium in the supplying industry, then implies from (2), (3), (5), (6) and (17) that

$$\frac{dW}{dc} = \left\{g_1(X_1)\eta_1(X_1)/n\right\}\frac{dX_1}{dc} + \left\{g_2(X_2)\eta_2(X_2)/n\right\}\frac{dX_2}{dc} \qquad (24)$$

Now, from (5), as $dc_1 = dc_2 = dc$, $dX_1/dc = 0$, while, from (6) and our assumptions on the form of $g_2(X)$, $dX_2/dc = dX_2/dc_2 < 0$. Thus

$$\frac{dW}{dc} = \left\{g_2(X_2)\eta_2(X_2)/n\right\}\frac{dX_2}{dc} < 0 \qquad (25)$$

R & D expenditure per firm is thus below the second-best optimum (given the number of firms, perfect foresight of buyers and the Cournot-Nash equilibrium). Of course as n becomes very large so this feature disappears, but otherwise the restriction on final output arising from the monopoly power of suppliers can be mitigated by slightly increasing R & D expenditure beyond the private profit maximum in order to reduce marginal costs and increase final sales, and this could be achieved by subsidising R & D. Thus

Proposition 6

A Cournot-Nash equilibrium with buyers perfect foresight and a fixed number of supplying firms, leads to too small a level of R & D expenditure per firm; a (small) subsidy on such expenditure would lead to a welfare improvement by increasing the level of final sales.

Proposition 6 encaptures an example of how an externality from one part of the technological development process (R & D) may counter sub-optimality in the performance of another (diffusion by oligopolists). If this welfare link is ignored it might appear that social and private cost-benefit calculations are compatible so that no regulatory policy on R & D is required.

If the n firms were initially earning zero profit then the subsidy may lead to positive profits and, if we relax the assumption of fixed n, possible entry. Such entry will generally compound the welfare benefit of the subsidy by reducing monopoly power and increasing final sales. It would, however, also lead to further duplication of R & D effort which may yield a less efficient outcome. Thus Proposition 6 cannot be extended to a free entry equilibrium.

V. CONCLUSIONS

Our purpose in writing this paper has been to argue that the generation and use of technology are not to be treated separately and should in fact be analysed jointly. We have used a simple two-period model to show that (a) the incentives to R & D arise from the surplus generated by the suppliers of the new good in the diffusion process and (b) that the diffusion path is related to the nature of the advances being generated from the R & D process. We have illustrated how as the parameters underlying the buyers' demand for new technology change so the diffusion path is affected in two ways; firstly directly and secondly through the effect on the incentives to R & D and the outcome of the R & D process. We have also shown how changes in the cost parameters underlying the diffusion process change the nature of new technology. This in turn affects the incentives to buy and thus the time path of the take-up of technology. The market for the technology determines the incentives to R & D.

We have also attempted to draw out some welfare implications of these arguments, and to highlight the role of expectations in the technological change process. By investigating models with and without free entry we have also hoped to stress the role of the oligopoly game in technological advance. It is our conclusion that the results above suggest that separate analysis of the components of the Schumpeter trilogy should be considered at best to represent only part of the answer to any problems in the economics of technological change.

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University of Warwick

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FOOTNOTES

1. Where welfare is measured by the sum of consumer and producer surpluses given the basic technology being diffused.

2. In this framework this cannot be achieved, there being only 'two' periods and thus two prices but $N > 2$ potential buyers.

3. (20) is derived by substitution of (7) and (8) into (9) and use of (18); (21) is derived from (7), (8), (9) and (19).

4. In fact if n were fixed but R & D endogenous (equation (21) holds) then the results of Table 1 are reinstated. If R & D is fixed but n is endogenous (equation (20) holds) then increased demand in the first period leads to increased x_1, X_1 and X_2 but decreased x_2, while higher second period demand leads to increased X_1, x_2 and X_2 but decreased x_1.

References

Dasgupta, P. and Stiglitz, J. (1980) "Industrial Structure and the Nature of Innovative Activity", Economic Journal, 90, 266-93.

David, P.A. (1969) A Contribution to the Theory of Diffusion, Stanford Center for Research in Economic Growth, Memorandum No.71, Stanford University.

Davies, S. (1979) The Diffusion of Process Innovations, Cambridge University Press.

Ireland, N. and Stoneman, P. (1984) "Technological Diffusion Expectations and Welfare", mimeo, University of Warwick.

Kamien, M. and Schwartz, N. (1982) Market Structure and Innovation, Cambridge University Press.

Stoneman, P. and Ireland, N. (1983) "The Role of Supply Factors in the Diffusion of New Process Technology", Economic Journal, Conference Supplement, 65-77.