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NOTE

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AGRICULTURAL PRODUCT PRICES AND FARM TECHNOLOGICAL CHANGE

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1. INTRODUCTION

One tradition of thought in agricultural economics asserts that, for some farmers at least, falling output prices stimulate the adoption of new farm technologies. The original source of this tradition, Cochrane (1958), was examined for internal consistency, and consistency with broad trends in data used to justify the argument (Section 2). Not only is the argument found wanting in its own terms, but is inconsistent with other analyses of farm technological change to which attention is drawn.

In Section 3, a neoclassical approach to modelling technological change as an endogenous process was outlined. This alternative approach emphasised the modelling of the supply of, and demand for, new technologies as the activities of distinct economic entities. Further, this approach distinguished between the supply of and demand for new technologies with well-protected property rights (denoted "embodied" technologies for convenience) and the supply of and demand for new technologies with poorly-protected property rights ("disembodied" technologies). In all cases, both the production of, and demand for, new farm technologies were shown to be increasing functions of agricultural output prices *ceteris paribus.*

Unless activities leading to new farm technologies are not endogenous investment activities, or farmer behaviour is not consistent with profit maximizing assumptions, it appears inappropriate to conclude that lower output prices stimulate farm technological advance.

2. OUTPUT PRICES AND TECHNOLOGICAL CHANGE

2.1 Cochrane's treadmill

In an influential analysis of agricultural technological change, Cochrane (1958, pp. 94-107) argued that the following factors created a technology "treadmill" where firms were forced to adopt new technologies in the face of falling agricultural output prices:

(i) there is a continuously-available stream of new technologies for farm firms;

(ii) farmers are generally price takers, therefore the only way to increase returns (for the first adopters) or maintain returns (for later adopters) is to reduce costs by adopting new technologies;

(iii) the aggregate demand for agricultural products is price inelastic; and

(iv) the rate of shift of supply resulting from the adoption of new technologies exceeds the rate of shift of demand resulting from increased *per capita* incomes (low income elasticity of demand for agricultural products), low population growth rates in developed countries, and a low rate of growth of export demand.

In Cochrane's homely metaphor, the consequence of these factors was:

> It is easy to see why the first farmers undertake a new method or practice. They benefit directly. And we can understand why neighbors of the enterprising first farmers adopt the technology: they see the income advantage and make up their minds to give it a try. But as more and more farmers adopt the new technology, output is affected and the price of the commodity declines. This price decline acts as a burr under the saddle of followers, the average farmers; the price of their output is declining, but their unit costs of production are unchanged. *To stay even with the world these average farmers are forced to adopt the new technology.* The average farmer is on a treadmill with respect to technological advance. (Cochrane, 1958, p.96, original emphasis).

Cochrane's thesis appears to remain an influential, although often unstated, law of agricultural economics (*e.g.* Herdt and Cochrane, 1966 p.248; Dexter, 1967; de Janvry, 1978).

Cochrane's use of the term "treadmill" has, arguably, also been taken to imply that the reduction in output prices resulting from technological change sets up a *continuing* process of interaction between output prices and technological change[1].

2.2 General Critique of a Technological Treadmill

Alternative models explicitly or implicitly linking technological change to (agricultural) product prices are inconsistent with at least the "vulgarized" version of Cochrane's (1958) treadmill. Outside agriculture, Schmookler's (1966) thesis of a positive correlation between innovative activity and expected returns is, pari passu, an implicit hypothesis of a positive correlation between innovative activity and expected output prices ceteris paribus. Griliches (1957, pp. 516-519) hypothesized in his study of hybrid maize that the rate of acceptance of new hybrid maize varieties was a (positive) function of profitability. Since there was little cross-sectional variation in price, this reduced to the hypothesis - confirmed in his analysis - that the diffusion rate was a positive function of the yield differential between F_1 hybrid and open-pollinated varieties. If Griliches' hypothesis is true in general, as well as in the particular case of yield differentials between maize varieties, then the level of innovation is an increasing function of the level of output price ceteris paribus. Binswanger (1978a,b) modelled disembodied technological change produced in the farm sector using neoclassical models. In the one output, two input case, he concluded that:

> ... the rise in output prices will increase the optimal research levels and, consequently, the rate [sic] of technical change. (Binswanger, 1978b, p. 150)

With multiple outputs, an increase in the price of one output was hypothesized to increase research in "those lines that favor the given output" (Binswanger, 1978b, p. 153).

As a third force - or, perhaps, a fifth column - in the argument about an hypothesized link between demand and output prices, and technological change, there are the "supply-siders" of technological change theory. Mowery and Rosenberg (1982, p.194), for example, argued that there was no evidence to support the contention "that market demand forces 'govern' the innovation process".

2.3 Critique of Cochrane's analysis

Since Cochrane's model generated conclusions that are contrary to those of the models outlined below - where the level of innovation is an increasing function of output prices - some explanation of possible sources of these differences is desirable.

1. The behavioural assumptions underlying Cochrane's model are somewhat unclear. The implication that early adopters actively seek new technologies suggests optimizing behaviour - e.g. profit maximization - but, as shown below, profit maximization generates the result that the level of innovation is an increasing function of output prices. The suggestion that followers, the average farmers, are forced to adopt new technologies "to stay even with the world", suggests income satisficing behaviour, although it is also potentially consistent with short-run profit maximizing behaviour with binding constraints (but not in the case of such a model outlined below). Cochrane (1958, p. 100) also asserted that "farm technological advance sows the seeds of its own slow-down" by driving output prices down so far that farmers' asset positions become weak "and the process of farm adoption of new technologies must be choked off".

The inference of this assertion is that, in the long run, the level of innovation is an increasing function of the level of output prices. Note, however, that Cochrane's (1958, p.100) assertion that contemporary technological change in the US was being financed out of a run-down of assets accumulated during the Second World War and not out of expected future returns is consistent with other hypotheses - e.g over-capitalization during the boom years of the war. Further, it is not clear that the asset positions of all farmers - especially the early adopters - would become sufficiently "weak" through the reduction in output prices following technological change to "choke off" technological change. For example, if only the assets of "below average", late adopting farmers were seriously "weakened", their assets might be liquidated through absorption into "above average", early adopting farms. If this situation occurred, the process of aggregate technological change in the long run would come to represent that of the early adopters, that is an increasing relationship between output prices and innovation. The effect of falling output prices of technological change in Cochrane's model is therefore critically dependent upon the fate of the followers with falling output prices. There is no recognition of the need for a linkage between the short and long runs in Cochrane's model. By contrast, the models below of demand for innovation explicitly separate the short run (given levels of investment in quasi-fixed inputs) from the long run (variable investment in quasi-fixed inputs) but, in both cases, the demand for innovation is an increasing function of the level of output price.

2. In the extended quotation above, Cochrane implied that farmers do not perceive the connection between current technological change in agriculture generally, and subsequent output expansion leading to falling output prices. If this "partial-dynamics-by-myopia" model is used in the context of the models below, farmers' continual downwards revisions of expected output prices as the effects of general technological change become apparent still result in lower investments in innovation. Thus it is not myopia that is at the heart of the difference between Cochrane's model and those below.

3. In Cochrane's model, the act of innovation is implicitly considered as a cost-less economic activity in the "manna from heaven" tradition of disembodied technological change (cf. Kennedy and Thirlwall, 1972, p.13). Neither the supply of, nor demand for, new innovations can sensibly be considered as cost-less processes.

4. Most importantly, Cochrane's analysis was extremely partial in that, in both his implicit model and his analysis from historical evidence, the implied *ceteris paribus* included the prices of all inputs except land, the cost of farmer adoption of new technology, and the responses of technology producers to changes in factors affecting farm profitability and factors affecting their supply of new technologies. It is highly unlikely that any of these factors were constant in the period considered by Cochrane.

At least as far as UK agriculture was concerned in the period 1950-70, estimated quality-corrected prices of investment in plant and improvements fell relatively to the prices of materials and labour, and also to the rental price of land. The prices of materials also fell relatively to those of labour and land (Godden, 1985, Figure 2.2(a)). Since plant, improvements and materials were the inputs most likely to introduce embodied technological change into agriculture, it would hardly be surprising that embodied technological change occurred in UK agriculture even with falling output prices. Further, the quality-corrected price of plant investment fell relative to falling output prices, and the quality-corrected price of improvements investment was approximately constant relative to output prices. By contrast, the prices of land - rental or asset - and labour relative to output rose sharply 1950-80, and the relative price of materials rose slowly (Godden, 1985 Figure 2.2(a)). The relative prices of some components of the materials category (e.g. seed, feed) also fell over the period 1950-70 (Godden, 1985, Figure 2.2(b)). Clearly, even with a falling output price, there was profitable scope for increased and costly embodied technological change.

Since there are no data on the costs of investment in disembodied technological change, there is no incontrovertible evidence linking investment in disembodied technologies with its costs. On the demand side, however, there is impressionistic evidence to suggest that, for much of the twentieth century, the costs of farmers' acquiring new disembodied technologies have fallen, and probably dramatically. With increasingly literate and/or better educated workforce and management, developments in mass communications (especially radio and television), reductions in the real cost of printing (and hence of newspapers, trade and technical journals, and public advisory services' publications), and developments in transport (especially motor vehicles), it seems reasonable to conclude that farmers' private costs of finding, evaluating and implementing new disembodied technologies have fallen secularly and dramatically. The growth of publicly-financed farmer advisory services have also reduced the cost of acquiring new disembodied technologies. Whether the costs of accessing these new technologies have fallen relative to output prices is difficult to judge, and thus it is impossible to conclude that only these changes in costs would have been sufficient to have ensured continuing technological advance in the face of falling output prices. Clearly, however, the cost of acquiring new disembodied technologies has fallen relative to the increasing costs of labour and land, providing a rationale for the adoption of new disembodied technologies as substitutes for labour and land inputs.

3. NEW INNOVATIONS - MODELLING DEMAND AND SUPPLY

In this Section are considered models of the demand for and supply of new farm innovations. De Janvry's (1978, Figure 11-1) concept of an innovation-creation process was augmented by including private sector research in addition to the public sector research institutes. Echoing the property rights literature, it was hypothesized that, where property rights in new knowledge are relatively well-protected by patents or similar instruments, private sector research can and will generate new farm technologies - e.g. farm chemicals, farm machinery. These technologies will largely, although not exclusively, be embodied in capital or material inputs. Conversely, where there are only relatively weak property rights in new farm technologies, such research will tend to be provided only by the public research institutes. Typically, but not exclusively, this research will emphasize disembodied technologies such as management and husbandry practices. For convenience, technologies that are well (poorly) protected by property rights will be designated as (dis)embodied technologies.

3.1 Firm-level demand for new disembodied technologies

A farm firm's demand for new disembodied technologies was derived in Appendix 1 from a conventional, neoclassical, cost-minimizing, deterministic model of an atomistic firm adapted from Berndt et al. (1979, 1980). The firm was assumed to have a single output production function whose arguments are the variable and quasi-fixed inputs. Additional arguments in this production function were the levels of investment in the quasi-fixed inputs, representing the internal cost - in terms of foregone output - of changes to quasi-fixed input stocks (Berndt et al., 1979, p.4).

Using this model, two different interpretations were examined of disembodied technological change. In the first, disembodied technology was viewed as a conventional quasi-fixed input contributing directly to the level of output. In the second interpretation, disembodied technology was viewed as affecting the values of the parameters of the production process (cf. Binswanger, 1978a,b).

In both these interpretations of disembodied technology, technological change occurs through the firm investing resources in acquiring new technologies. These resources may be the time expended in the collection, evaluation and implementation of new technologies, with an associated opportunity cost of the value of this labour. Alternatively, resources may be expended in the purchase of services, such as the purchase of information or travel to collect or examine new technological information. Under the first interpretation of disembodied technology, investment in new disembodied technologies increases the stock of disembodied technology, and raises output according to the coefficient of this stock in the production process. In this first interpretation, the stock of disembodied technology can be viewed as having a depreciation element since new technological investment results in some of the previously acquired information becoming superseded. Note also the distinction in this model between investment in human capital - i.e. the cost of equipping workers and management with the current levels of knowledge and skills - and investment in new disembodied technologies - i.e. the cost of acquiring completely new knowledge and skills. Under the second interpretation of disembodied technology in the model, the cost of production is partly a function of past accumulated expenditures on acquiring new disembodied technologies - i.e. a function of the stock of disembodied technologies. Under this interpretation, depreciation of the disembodied technology stock can be viewed as the discarding of knowledge and practices retarding cost reduction.

Not surprisingly, since the problem was constructed in a conventional neoclassical framework, with investment in new disembodied technologies as a conventional investment process, investment in such technologies exhibits conventional properties (cf. Appendix 1). In particular, investment in all types of capital goods (quasi-fixed inputs) rises as the profitability of production rises, therefore, investment in new disembodied technologies may be expected to rise (fall) when output prices rise (fall) ceteris paribus.

The preceding argument may be illustrated as follows. Consider, as case (i), a firm deciding at time t its future production and investment decisions, including decisions relating to the level of investment in new disembodied technology. The firm will have expectations about future product prices, and the prices of variable and quasi-fixed inputs (the latter including investment in new disembodied technology). The firm will notionally prepare a plan of anticipated output, and the optimal levels of variable inputs and investment in quasi-fixed inputs (including disembodied technology). Suppose, as case (ii), the firm were to have considered this production plan at time t with all expected output prices lower than in case (i), but all other input prices being the same. Then the optimal levels of production, variable inputs, and investment in quasi-fixed inputs (including investment in new disembodied technology) would be lower than in case (i). Conversely, as case (iii), were the firm to consider its production plan at time t with input prices as in case (i) but with higher output prices, its optimal production plan would have had higher input levels, including higher levels of investment in new disembodied technologies. Additionally, were the firm to sequentially revise its production plan of period t in periods t+j and t+k, and were only its expectations of future output prices to be raised or lowered in these subsequent decision periods, then the firm's optimal investment plans (including those for new disembodied technologies) would also be respectively raised or lowered.

At the level of aggregate agriculture, an additional argument may be proposed for a positive relationship between output prices and disembodied technological change. If the aggregate supply of land in agriculture is fixed, increases in output prices can be expected to increase land prices relative to those of all other inputs (cf. the doubling of real UK land prices in the year preceding entry to the EC - Godden, 1985, Figure 2.2). If the price of land rises relatively to other inputs because of output price increases, these other inputs will tend to be substituted for land. In particular, land-saving technologies will be substituted for land, and thus the level of investment in new technologies will be an increasing function of output price (cf. de Janvry, 1978).

3.2 Production of Disembodied Technologies

There are four potential sources of new disembodied technologies for the individual firm. The first is the firm itself. Assuming a positive marginal product for own research expenditures and, since the demand for new disembodied technologies is an increasing function of output price (*cf.* preceding Section), so too is its production. A second potential source of new disembodied technologies is other farm firms. But if all farm firms have similar production characteristics, their demands for new disembodied technologies will also create their own supplies. With appropriate information flows, these new disembodied technologies may be borrowed (at a cost to the borrowing firm) or traded between firms. The production of new disembodied technologies in "rival" firms will also be an increasing function of output price.

A third potential source of new disembodied technologies is the private non-farm sector. If, as suggested above, these new technologies are poorly protected by intellectual property rights, there are unlikely to be private firms solely devoted to generating such technologies. Rather, new disembodied technologies are likely to be generated in the private sector as adjuncts to the development of new embodied technologies. If, as the argument below suggests, the production of new embodied agricultural technologies is an increasing function of output price, it is probable that the joint production of new disembodied technologies would also be an increasing function of agricultural product prices.

The fourth potential source of new disembodied technologies is the public sector research institutes. In recent research, the allocation of public funds to agricultural research has been hypothesized to occur within a "regulatory" market (e.g. Guttman, 1978; Huffman and Miranowski, 1981; Johnston, 1981; Rose-Ackerman and Evenson, 1985). These studies posit the existence of relationships governing the supply of and demand for public expenditure for agricultural research. It is possible, however, that the level of this funding is predominantly exogenous, and derives largely from the previous level of expenditure. But, even within a model of largely exogenous research funding, there is likely to be some discretion in the provision of funds. It is proposed therefore that research funding (RF_t) was composed as:

$$RF_t = RF_{t-1} + R_t$$

where R_t is discretionary research funding. The determinants of the level of R_t and its relationship, if any, to agricultural product prices (P_t), were explored in a model similar to those of the preceding authors (Appendix 2).

As argued in Appendix 2, the politico-bureaucratic structure delivering agricultural research funding can be conceived as being analogous to a monopolist firm with an upward-sloping marginal cost schedule for supplying agricultural research funds. But then, by conventional microeconomic theory, an increased (decreased) final demand for agricultural products results in increased (decreased) derived demands for all inputs, including new disembodied technologies (cf. preceding Section). Thus increased (decreased) agricultural product prices will increase (decrease) the level of discretionary spending on public agricultural research. Assuming that the production of new disembodied technologies is an increasing function of discretionary public research funding, then increased (decreased) agricultural output prices ceteris paribus will result in increased (decreased) output of new disembodied technologies.

Indirect but tentative support for the hypothesis of a positive relationship between output prices and research funding may be obtained from the estimated models of Huffman and Miranowski (1981) and Rose-Ackerman and Evenson (1985). In the reduced form equation for Agricultural Experiment Station research expenditures in the former, solution for the derivative with respect to agricultural prices when evaluated at the mean of the variables yielded a positive derivative. In Rose-Ackerman and Evenson (1985), the share of agricultural research expenditures in total state budgets was a positive function of farm income share in the State, which is also consistent with a positive relationship between agricultural research spending and agricultural output prices ceteris paribus. In both cases, the consistency of the estimated models with the present hypothesis must be regarded as very tentative support for the hypothesis since the models were not constructed with this test in mind.

Even within a model of fixed expenditure on public agricultural research, the output of disembodied technologies may be reasonably argued to be an increasing function of output price. Within an agricultural research budget there will be components identifiable with particular agricultural commodities. For each commodity there will be a political demand for new publicly-developed technologies broadly associated with farm-level demands for new technologies. Products whose price is rising (relative to other products) will have relatively rising demands for new disembodied technologies. Unless political or organizational considerations by which individual firms' demands for public research are translated into an aggregate demand significantly bias the unweighted demands of individual firms, the research resources devoted to agricultural products with (relatively) rising prices will, by the argument of Appendix 2, increase compared to products with (relatively) falling prices.

Other, less-rigorous arguments also suggest an increasing relationship between research funding and output prices in agriculture:

(i) within the agricultural sector, it seems reasonable to suppose that research funding for particular industries would be broadly proportional to the relative size (in value terms) of each industry; for a particular industry whose output prices rose, it would seem reasonable to expect an increase in its research expenditures. Again, assuming production of new technologies is an increasing function of research inputs, an increasing relationship could be expected between development of new disembodied technologies and output prices. For example, on a "fair share" argument, agricultural interest groups might propose, and politicians and bureaucrats might accept, that the agricultural share of total public sector research expenditure should be proportional to the share of the value of its output;[2] thus, if agricultural prices and output rose _ceteris paribus_, agricultural research funding would also rise; and

(ii) public research is sometimes funded by farmers' contributions to research funds for their industries, where funds are raised as a fixed levy per unit of output; if farm output prices rose, it would be easier to collect an increased levy, and the public sector research establishment would probably urge such increases if they were budget-maximizers.

There may, however, be "perverse" responses in the provision of public agricultural research funds. Where agricultural incomes are low and/or falling - _e.g._ as a consequence of falling output prices - there may be pressure from agricultural interest groups for increased research to develop new, disembodied, cheap-to-adopt technologies to alleviate these adverse income trends. However, the demands by interest groups for increased research in these circumstances may well be countered, at least indirectly, by politicians' and bureaucrats' recognition that, even if new technologies were developed, farmers with low or falling incomes would be in a poor financial position to adopt new innovations unless these were truly costless to adopt. Agricultural interest groups themselves may realize that, especially with low incomes, increased research may do little to improve agricultural incomes and that more fundamental measures - such as structural change involving a change in the average scale of farming, itself having attributes of disembodied technological change - may be required.

The mechanisms governing the provision of public agricultural research funds have been relatively little analyzed. There is consequently relatively little theoretical or empirical evidence of the nature of the relationship between agricultural output prices and the provision of public funding. The argument of this Section lends some support to the contention that, if individual farmers' demands for disembodied technological change are an increasing function of output prices, so too is the aggregate demand for public research. Since public agricultural research funding may be reasonably argued to be an increasing function of output prices, it can reasonably by hypothesized that the production of new disembodied technologies will also be an increasing function of output prices *ceteris paribus*.

3.3 Demand for New Embodied Technologies

The demand for new technologies embodied in produced farm inputs was analyzed using the same model as that of the demand for new disembodied technologies (*cf*. Section 3.1). The effect of technological change embodied in new inputs is identical to a reduction in the price per unit of the service flow resulting from a change in technology in the input-producing industry. An immediate corollary is that embodied technological change invariably causes an increased use of the input in which technological change in embodied, where the level of use is measured in units of the service flow.

It is an obvious outcome from this standard neoclassical model that, where a demand for a new embodied technology actually exists, this demand will be an increasing function of the price of final agricultural output (<u>cf.</u> Appendix 3).

3.4 Production of New Embodied Technologies

In general, but not exclusively, purchased farm inputs - both variable and quasi-fixed - are produced in non-price-taking industries. The modelling of the production of farm inputs by these industries, and their R& D activities producing embodied technological change, therefore requires a model in which the price level and the level of R&D expenditure are determined endogenously. The model chosen to examine this simultaneity was derived from models of Dasgupta and Stiglitz (<u>cf.</u> Dasgupta, 1982). Technological change in the input producing industry may be modelled either as process innovation in that industry, or the development of new forms of the farm input by product innovation. Both these possibilities were considered.

To generate tractable results, the model is restrictive in its assumptions. For example, simple exponential forms were assumed for the demand schedule for the farm input and the unit cost function; an exogenously-given number of identical firms was assumed for the input-producing industry, where all these firms entertained Nash-Cournot conjectures concerning the decisions of other firms; and each firm achieved complete appropriability of the benefits of its R&D expenditures. Note that, by assumption, Dasgupta and Stiglitz's model does not collapse into the perfectly competitive solution with large numbers of firms since the unit cost function is assumed to have an infinite value at zero R&D expenditure. However, the model closely approximates the perfectly competitive solution if the number of firms (N) is large - in this case, price tends to marginal (equals constant average) cost, as long as N exists within the bounds defined by the parameters of the demand and unit cost functions.

In the analysis (Appendix 4), a solution is first derived for the process innovation case of embodied technological change, closely following the Dasgupta and Stiglitz model. This model is then used to generate a solution for the product innovation case. In both cases it is shown that the production of new embodied technologies is an increasing function of the price of final agricultural output.

4. IMPLICATIONS AND CONCLUSIONS

For farm firms whose *modus operandi* is consistent with the assumptions of a standard neoclassical model of an atomistic firm, the above arguments lead to the conclusion that the demand for new technologies is an increasing function of the price level of final agricultural output. To the extent that the production of new technologies in the private sector ("embodied" technologies) and in publicly funded research ("disembodied" technologies) is responsive to the price of final agricultural output, the production of new innovations is also most likely to be an increasing function of final output prices. Thus, the observed level of investment in new technologies *ex post* is likely to be an increasing function of agricultural output prices.

This result is contrary to Cochrane's (1958) argument that followers will be forced to adopt new technologies in the face of falling agricultural output prices. Further, the argument of the preceding paragraph is contrary to the vulgarized version of Cochrane's argument that implies the existence of a continuing endogenous process of falling output prices continually stimulating further technological change.

Several issues arise, however, from the preceding modelling framework. The first issue concerns whether or not it is appropriate to treat the demand for, or production of, new technologies as economic processes. In particular, is it appropriate to model the demand for new technologies as investment processes or, indeed, as investment processes within a neoclassical model? On the production side, certainly, is it reasonable to consider the development of new technologies as susceptible to conventional economic variables? There may well be large elements of exogeneity or habit governing both investment in, and the production of, new technologies. However, it does seem appropriate to assert that, at least at the margin, there are discretionary expenditures affecting technological change which are affected by economic decisions. Further, in the longer run, it seems reasonable to assume that investments in activities affecting technological change are expected to show a positive return, and that resources will - albeit sluggishly - be attracted into areas that demonstrate relatively higher rates of return.

Concerning the farmer demand for new technologies, it may seem superficially attractive to speculate that, with regard to new technology, farmers are not optimizers but follow some other form of behaviour pattern such as satisficing. It would seem contradictory, however, to assert that farmers are satisficers with respect to technology investment decisions, but optimizers with respect to conventional production decisions. If farmers are not optimizers with respect to all decisions, then not only is the preceding technology investment analysis inappropriate, but so is neoclassical farm supply response analysis. Whilever the latter is maintained, it seems appropriate to maintain a neoclassical analysis for analysing technology demand, and production.

It seems appropriate, therefore, to conclude that, if farmers are profit maximizers consistent with the neoclassical tradition, then their investment behaviour regarding new technology is similar to that affecting other investment goods. In particular, the level of investment in new technology is likely to be an increasing function of the level of profitability, and hence the level of agricultural output prices *ceteris paribus*.

Footnotes

1. Whether or not Cochrane intended to imply that the treadmill process he identified is a continuing one is not central to the present argument.

2. A recent, related case is that the Australian Government decided that, if farmer research groups acted similarly, agricultural research funding would be raised to 0.5% of the gross value of production of designated agricultural industries (Kerin, 1985).

APPENDIX 1

Demand for New Disembodied Technologies

A farm firm's demand for new disembodied technologies is hypothesized as deriving from a conventional, neoclassical, cost-minimizing, deterministic model of an atomistic firm adapted from Berndt _et al._ (1979, 1980). The firm is assumed to have a single output production function whose arguments are the variable and quasi-fixed inputs. Additional arguments in this "production" function are the levels of investment in the quasi-fixed inputs, representing the internal cost - in terms of foregone output - of changes to quasi-fixed input stocks (Berndt _et al._, 1979, p. 4).

In this model, two different interpretations are examined of disembodied technological change. In the first, disembodied technology is viewed as a conventional quasi-fixed input contributing directly to the level of output. In the second interpretation, disembodied technology is viewed as affecting the values of the parameters of the production process (_cf._ Binswanger, 1978a,b). In both these interpretations of disembodied technology, technological change occurs through the firm investing resources in acquiring new technologies.

Consider a firm producing a single output Y_t using a vector of variable inputs y_t with exogenous prices p_t, a vector of quasi-fixed inputs x_t with exogenous acquisition prices q_t, and an accumulation vector $\dot{x}_t$ $(= \partial x_t / \partial t)$ for the quasi-fixed inputs, with a "production" function:

$$(1.1) \quad Y_t = F(y_t; x_t, \dot{x}_t)$$

where $\partial Y_t / \partial \dot{x}_t$ (<0) is the internal (opportunity) cost of foregone output resulting from changing the stocks of the quasi-fixed inputs. In the present analysis the conventional assumptions are made that $\partial Y_t / \partial y_t > 0$, $\partial Y_t / \partial x_t > 0$, and that the production set is convex in y_t and x_t. Berndt <u>et al</u>. (1979, pp. 4-6) showed that, for the objective functional:

$$(1.2) \quad \min_{y,x,\dot{x}} \; L_0(Y) = \min_{y,x,\dot{x}} \int_0^{\infty} e^{-r.t}\{\sum_{j=1}^{m} p_{jt}.y_{j}t \; + \sum_{i=0}^{n} q_{it}(\dot{x}_{it}+d_{it}.x_{it})\}dt$$

where d_t is the vector of depreciation rates of the quasi-fixed inputs and r is the firm's discount rate, then the cost minimizing short-run variable input demand functions are given by:

$$(1.3) \quad y_t^* = y(p_t; x_t, \dot{x}_t, Y_t)$$

Now, since $\partial Y_t / \partial y_t > 0$, then $\partial y_t / \partial Y_t > 0$; but as y_t^* is a subset of y_t (y_t^* is the optimal value of y_t for given values of $p_t, x_t, \dot{x}_t$ and Y_t) then:

(1.4) $\partial y_t^* / \partial Y_t > 0$

Berndt et al. (1979, pp. 6-8) then showed that, for the normalized restricted cost function:

(1.5) $G_t = \sum_{j=1}^{m} p_{jt} \cdot y_{jt}^* = G(p_t; x_t, \dot{x}_t, Y_t)$

the second stage optimization problem is:

(1.6) $\min_{x,\dot{x}} \bar{L}_0 = \min_{x,\dot{x}} \int_0^\infty e^{-r \cdot t} \{G_t + \sum_{i=0}^{n} q_{it} \, (\dot{x}_{it} + d_{it} \cdot x_{it})\} dt$

Now, if x_t is an optimal path for the objective functional equation (1.6), then the following conditions are necessary along it (cf. Treadway, 1971, p. 847):

(1.7) $-G_x - r.G_{\dot{x}} - q.(r+d) + G_{\dot{x}\dot{x}}.\ddot{x} + G_{x\dot{x}}.\dot{x} = 0$

for $G_x = \partial G / \partial x$ etc., and dropping the time subscript.

Now the set of simultaneous equations implied by equation (1.7) indicates that, along the optimal path, the optimal stocks of the quasi-fixed inputs and their accumulation rates are given by:

(1.8a) $x_{it}^* = x_i(p_s, q_s; Y_s, r, d, x_w, \; s \geq t, \; w < t)$

(1.8b) $\dot{x}^*_{it} = \dot{x}_i(p_s, q_s; Y_s, r, d, x_w,\ s \geq t,\ w < t)$

By an analogous argument to that between equations (1.3) - (1.4) then:

(1.9) $\partial x^*_{it}/\partial Y_t > 0$

But, if $\partial x^*_{it}/\partial Y_t > 0$, then $\partial \dot{x}^*_{it}/\partial Y_t > 0$ since, for $Y_1 > Y_0$, then $x_{it+1}(Y_1) > x_{it+1}(Y_0)$ if and only if at least one of the $\dot{x}_{it-j}(Y_1) > \dot{x}_{it-j}(Y_0)$. But, since all the solutions obtained above to equation (1.6) are for stationary prices (*cf.* Berndt *et al.*, 1979), then:

(1.10) $\dot{x}_{it-j}(Y_1) > \dot{x}_{it-j}(Y_0)$ for all $j=1,\ldots,t-1$

and hence:

(1.11) $\partial \dot{x}^*_{it}/\partial Y_t > 0$

Now, in Berndt *et al.*'s (1979) solution, the input prices p_t $(i \neq 1)$ and q_t are normalized on p_{1t}. If the exogenous output price P_t is also normalized on p_{1t}, then for non-decreasing returns to scale, $\partial Y^*_t/\partial P_t > 0$, and hence:

(1.12a) $\partial y^*_t/\partial P_t = (\partial y^*_t/\partial Y^*_t).(\partial Y^*_t/\partial P_t) > 0$

(1.12b) $\partial x^*_t/\partial P_t = (\partial x^*_t/\partial Y^*_t).(\partial Y^*_t/\partial P_t) > 0$

(1.12c) $\partial \dot{x}^*_t / \partial P_t = (\partial \dot{x}^*_t / \partial Y^*_t).(\partial Y^*_t / \partial P_t) > 0$

That is, optimal levels of variable inputs, and optimal stocks of and investment in quasi-fixed inputs are increasing functions of the output price.

Two alternative views are proposed for considering disembodied technological change in this framework. Firstly, for simplicity, suppose that one of the quasi-fixed inputs (x_0 say) represents the stock of disembodied technology which directly affects production, and has an associated increment $\dot{x}_0$. From equations (1.12), the optimal paths of the disembodied technology stock and its increment satisfy the equations:

(1.13a) $x^*_{0t} = x_0(p_s, q_s; Y_s, r, d, x_w,\ s \geqq t,\ w < t)$

(1.13b) $\dot{x}^*_{0t} = \dot{x}_0(p_s, q_s; Y_s, r, d, x_w,\ s \geqq t,\ w < t)$

Although the land asset (<u>i.e.</u> acquisition) price (q_{At}) is exogenous to the firm, it will be correlated with the output price (P_t):

(1.14) $\partial q_{At} / \partial P_s > 0$ for all $s \geqq t$

It is assumed that the acquisition prices of all other inputs (both variable and quasi-fixed) are perfectly price elastic in the relevant ranges so that there is no correlation between them and P_t. Then:

$$(1.15a)\qquad \partial x^*_{0t}/\partial P_t = (\partial x^*_{0t}/\partial q_{At}).(\partial q_{At}/\partial P_t) + (\partial x^*_{0t}/\partial Y_t).\ (\partial Y_t/\partial P_t)$$

$$(1.15b)\qquad \partial \dot{x}^*_{0t}/\partial P_t = (\partial \dot{x}^*_{0t}/\partial q_{At}).(\partial q_{At}/\partial P_t) + (\partial \dot{x}^*_{0t}/\partial Y_t).\ (\partial Y_t/\partial P_t)$$

From inequality (1.12), the second terms on the right-hand sides of equations (1.15) are positive. It is reasonable to suppose that disembodied technology and land are gross substitutes, and hence preceding expressions for $\partial x^*_{0t}/\partial q_{At}$ and $\partial \dot{x}^*_{0t}/\partial q_{At}$ are positive. Hence both equations (1.15) are positive, and there is an increasing relationship between the level of output price and the level of, and investment in, disembodied technology.

Secondly, consider viewing disembodied technology as affecting the parameters of the production process, so affecting the cost function. For x_0 and $\dot{x}_0$ being the accumulated expenditures, and current investment, in new disembodied technologies, and where x_r are the stocks of quasi-fixed inputs excluding disembodied technology, and suppressing time subscripts for convenience, define:

$$(1.16)\qquad G(x_0) = G(p_t; x_r, x_0, \dot{x}, Y)$$

then:

$$(1.17)\qquad G(x^0_0 + \Delta x_0) < G(x^0_0) \quad \text{for some } x_0 = x^0_0 \text{ and } \Delta x_0 > 0$$

Consider, initially, the optimal solution to the objective functional equation (1.6) where superscript 0's indicate the optimal values of y_t, x_t and $\dot{x}_t$ given values of p_t and Y_0:

$$(1.18) \qquad L(Y_0) = \int_0^{\infty} e^{-r.t}\{p_t.y_t^0 - q.(\dot{x}_t^0 + d.x_t^0)\}dt$$

Now suppose that output rises to Y_1 ($>Y_0$) and suppose that an optimal solution conditional on unchanged levels of x_0 and $\dot{x}_0$ is $L(Y_1|x_0^0)$:

$$(1.19) \qquad L(Y_1|x_0^0) = \int_0^{\infty} e^{-r.t}\{G^1(x_0^0) - q_r.(\dot{x}_r^1 + d_r.x_r^1) - q_0.(\dot{x}_0^0 + d_0.x_0^0)\}dt$$

where $G^1(x_0^0) = G(p_t; x_r^1, \dot{x}_r^1, x_0^0, \dot{x}_0^0, Y_1)$ and the superscript 1's indicate the conditionally optimal values of x_r and $\dot{x}_r$ given Y_1 and unchanged values of the disembodied technology variables.

Now suppose that $(x_r^1, \dot{x}_r^1, x_0^0, \dot{x}_0^0)$ constitutes a solution to the unconditional optimum $L(Y_1)$. Then a characteristic of this unconditional optimum is the equality of discounted marginal costs and benefits:

$$(1.20) \qquad \int_0^{\infty} e^{-r.t}\{(G^1(x_0^0) - G^1(x_0^0 + \Delta x_0)) - q_0.d_0.((x_0^0 + \Delta x_0) - x_0^0)\}dt = 0$$

but since $G^1(x_0^0) - G^1(x_0^0 + \Delta x_0) > 0$ by equation (1.17) above, then $\Delta x_0 > 0$ for some t. That is, given $Y_1 > Y_0$, the optimal level of x_0 and, by implication, $\dot{x}_0$, is greater at Y_1 than Y_0. Thus the optimal stock of disembodied technology, and the optimal level of investment in it, is higher the greater the output level. Since the output level is assumed to be an increasing function of the output price, so too are the stocks of, and investment in new, disembodied technology.

Thus, in this inter-temporal model of a cost minimizing farm firm, the stock of disembodied technology and the level of investment in this stock are increasing functions of the output price regardless of which interpretation of disembodied technology is preferred.

APPENDIX 2

Supply of New Disembodied Technologies from the Public Sector

In recent research, the allocation of public funds to agricultural research has been hypothesized to occur within a regulatory market (e.g. Guttman, 1978; Huffman and Miranowski, 1981; Johnston, 1981; Rose-Ackerman and Evenson, 1985). These studies posit the existence of relationships governing the supply of and demand for public expenditure for agricultural research. It is possible, however, that the level of this funding is predominantly exogenous, and derives largely from the previous level of expenditure. However, even within a model of largely exogenous research funding, there is likely to be some discretion in the provision of funds. It is proposed therefore that research funding (RF_t) is composed as:

$$(2.1) \quad RF_t = RF_{t-1} + R_t$$

where R_t is discretionary research funding. The determinants of the level of R_t and its relationship, if any, to agricultural product prices (P_t), were explored in a model similar to those of the preceding authors.

The "demand" for agricultural research funds is defined to be a downward-sloping function of the annual supply of research funds. The rationale for this characteristic is that, from the individual farmer's viewpoint, the marginal utility of research funds (assuming that the present value of resulting technologies is an increasing function of research funds) is a decreasing function of the level of research funds (*cf.* Appendix 1). The individual farmer's demand for new disembodied technologies is as defined in equation (1.13b), and may be aggregated for all farmers. Further, since the organization of individual farmers' demands for disembodied research requires resources for it to become an effective political demand, the aggregate demand for research funds at the political level is a derived demand.

The "supply" of public agricultural research funds is provided by politicians and bureaucrats. It is assumed that these individuals form a sufficiently cohesive group with sufficiently similar objectives to be considered a "monopolist firm" providing agricultural research funds. The objectives of the politicians include their re-election, and they seek political support in the form of votes and election finance from, *inter alia*, those demanding agricultural research funding. The objectives of the bureaucrats include to sufficiently satisfy their political masters to secure their jobs and prospects; they achieve this, *inter alia*, by servicing the demands of groups seeking agricultural research funds. As a "monopolist firm", these politicians and bureaucrats obtain utility from servicing the demands of groups like those seeking agricultural research funds, in the form of political, financial and bureaucratic support.

However, the agricultural research funds which are implicitly traded for this support are obtained in another regulatory market where other groups of regulators are also seeking funds from a budget which may be considered of finite size. The agricultural research "monopolist" therefore faces a rising supply schedule for agricultural research funds. For greater levels of funds, it must pay a higher price per unit of agricultural research funds - *e.g.* if it buys support for its agricultural research funds by log-rolling, higher levels of these funds will require the agricultural research funding "monopolist" trading higher levels of support with others to obtain a greater intensity of support from existing supporters and/or attracting additional supporters. An obvious corollary of this argument is that the "monopolist firm" which supplies agricultural research funding has an upward sloping marginal cost schedule.

But, as previously argued, the derived demand schedule for public research funds has conventional characteristics. In particular, a rise in the price of final agricultural ouput - and, *pari passu*, increased output - shifts outwards the demand schedules for all inputs including new technologies. If, as previously argued, the marginal cost schedule of discretionary agricultural research funding is upward sloping, then an increased (decreased) demand for final agricultural output will increase (decrease) the demand for and supply of discretionary public agricultural research funding.

Adding the additional assumption that the production of new disembodied technologies is an increasing function of public agricultural research expenditures, then the production of new disembodied technologies is also an increasing function of agricultural output prices.

APPENDIX 3

Demand for New Embodied Technologies

The framework in which the embodied technology question is investigated is that outlined in Appendix 1 for disembodied technological change. In the latter, innovation of new disembodied technologies was regarded as an investment activity either directly affecting output, or affecting the coefficients of the cost function. In the present analysis of embodied technological change, a new embodied technologies are considered as equivalent to a reduction in the price of the homogeneous service flows of an input.

Suppose technological change is embodied in the m^th^ variable input. Then the demand for this input measured in terms of its service flow, and ignoring the time subscript, is:

$$(3.1) \qquad y^{*}_{m1} = y_m(p_i,\ i=1,\dots,m-1;\ p_{m1}, x, \dot{x}, Y)$$

where, with embodied technological change, the price of the m^th^ input has been reduced from some p_{m0} to p_{m1} (<u>cf.</u> equation (1.3) in Appendix 2). But, from equation (1.4):

$$(3.2) \qquad \partial y^{*}_{m1} / \partial Y > 0$$

Thus the demand for the new innovation is an increasing function of the output price since it is assumed that $\partial Y/\partial P > 0$.

Similarly, if technological change is embodied in the n^{th} quasi-fixed input, then the optimal level of this input at time t at the new acquisition price q_{n1t} ($<q_{n0t}$, the old price) measured in terms of the units of service supplied by the quasi-fixed input, and the level of investment in this input, are (cf. equations (1.8) in Appendix 1):

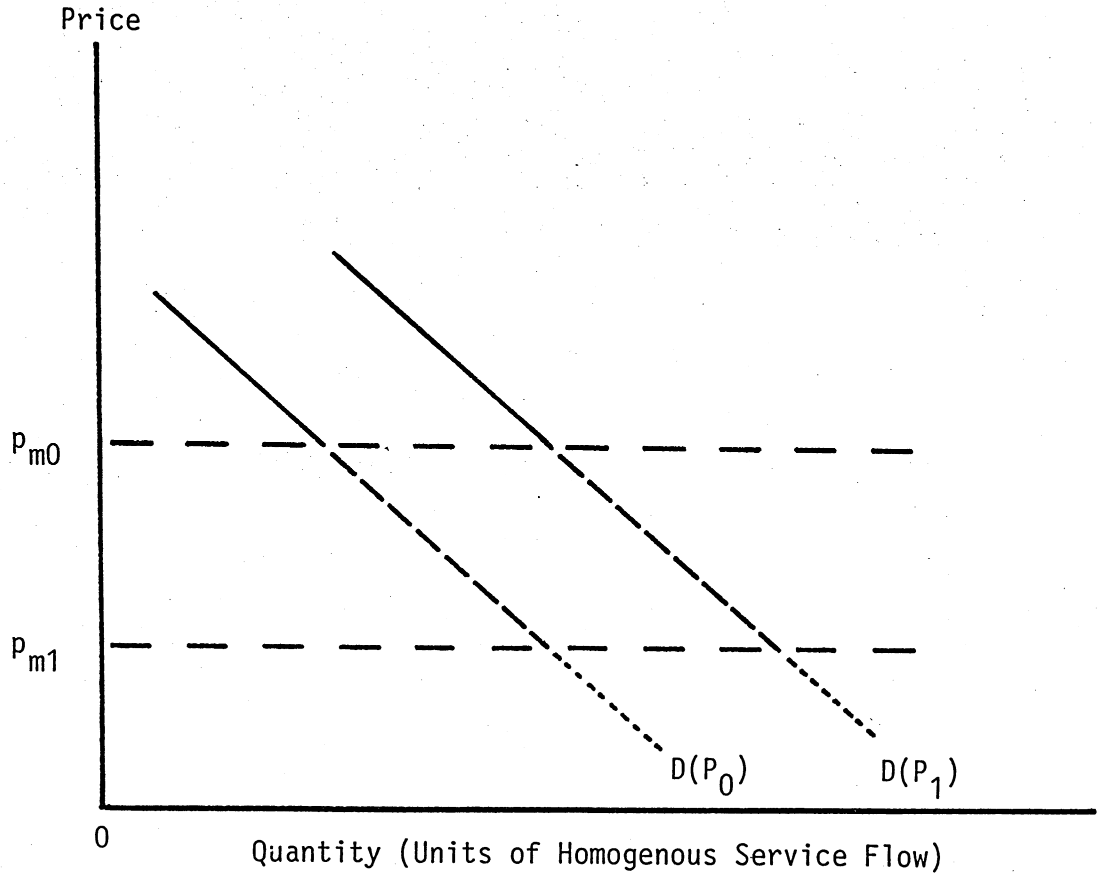
$$(3.3a) \qquad x^*_{n1t} = x_n(p_s, q_s; Y_s, r, d, x_w, s \geqq t, w<t)$$

$$(3.3b) \qquad \dot{x}^*_{n1t} = \dot{x}_n(p_s, q_s; Y_s, r, d, x_w, s \geqq t, w<t)$$

where both $\partial x^*_{n1}/\partial Y$ and $\partial \dot{x}^*_{n1}/\partial Y$ are positive (cf. equations (1.9) and (1.10) and ignoring time). Thus the optimal stock of, and level of investment demand for, an innovation embodied in a quasi-fixed input, are also increasing functions of the level of the final output price.

A graphical interpretation of this result is given in Figure 1 for a variable input. Suppose this input is initially supplied by a competitive industry at price p_{mo}. Then the line segments of demand schedules $D(P_0)$ and $D(P_1)$ – for output prices $P_1>P_0$ – are the actual input demand schedules in the sense that these quantity/price combinations are feasible given the current technology for producing input m. The line segments of $D(P_0)$ and $D(P_1)$ below p_{m0} are the latent demand for input

Figure 1: Embodied Technological Change



m in the sense that, if the production conditions in the input supplying industries changed, then these quantity/price combinations would be feasible. Consider a new technology which enables input m to be supplied at some price p_{m1}. Above p_{m0} there is no demand for the new technology, since the input embodying the old technology could still be supplied at p_{m0}. There is only a demand for the new technology for $p_{m1} < p_{m0}$ where the demand for the new technology is an increasing function of the price of final output.

APPENDIX 4

Production of New Embodied Technologies

(a) Process innovation in input producing industry

The model, following Dasgupta (1982), supposes an industry with a simple exponential aggregate demand schedule, and N (exogneously-given) price-fixing, profit-maximizing, identical firms with unit costs as a simple exponential function of R&D expenditures. Firms are assumed to entertain Nash-Cournot conjectures about the price and production decisions of rivals. The industry is assumed to be characterized by a symmetric equilibrium.

With industry demand schedule:

$$(4.1) \quad p(Z) = aY^{b}Z^{-d} \qquad a,b,d > 0$$

then firm i's demand schedule, assuming Cournot conjectures about aggregate output decisions of other firms (Z_0):

$$(4.2) \quad p(Z_i + Z_0) = aY^{b}(Z_i + Z_0)^{-d}$$

Also assume that the firm's research affects its production costs as:

(4.3) $c_i(v_i) = e.v_i^{-f} \qquad e,f > 0$

The firm's profit function is:

(4.4) $A_i = [p(Z_i + Z_0) - c_i(v_i)].Z_i - v_i$

First-order conditions for a maximum of (4.4) are:

(4.5a) $\partial A_i/\partial Z_i = p(Z_i + Z_0) + Z_i.p'(Z_i + Z_0) - c_i(v_i), = 0$

(4.5b) $\partial A_i/\partial v_i = - c_i'(v_i).Z_i - 1, = 0$

where Z_i^*, v_i^* are firm i's optimal values for Z_i, v_i respectively, derived from simultaneous solution of equations (4.5)

Assume a symmetric equilibrium for the industry; <u>i.e.</u> $Z_i^* + Z_0 = N.\overline{Z}$,

$c_i(v_i^*) = c(\overline{v})$. Substitute equations (4.2) and (4.3) in equations (4.5):

$$p(N.\overline{Z}) + \overline{Z}.(-d).aY^b (N.\overline{Z})^{-d-1} = c(\overline{v})$$

$$p(N.\overline{Z}) - (d/N) \; aY^b(N.\overline{Z})^{-d} = c(\overline{v})$$

$$(4.6) \quad p(N.\bar{Z}).\ (1 - d/N) \qquad = c(\bar{v})$$

$$(4.7) \qquad - c'(\bar{v}).\bar{Z} = 1$$

Solving (4.6) and (4.7) simultaneously using (4.1) and (4.3):

$$(\text{from } 4.7) \quad (-f)(-e.\bar{v}^{-f-1}).\bar{Z} = 1$$

$$(4.8) \qquad \bar{Z} = \bar{v}^{f+1}/(ef)$$

$$(\text{from } 4.6) \quad aY^{b}N^{-d}\bar{Z}^{-d}\ (1 - d/N) = e.\bar{v}^{-f}$$

$$\bar{Z}^{d} = ae^{-1}Y^{b}N^{-d}\bar{v}^{f}\ (1 - d/N)$$

$$(4.9) \qquad \bar{Z} = \alpha^{1/d}e^{-1/d}Y^{b/d}N^{-1}\bar{v}^{f/d}\ (1 - d/N)^{1/d}$$

(equating 4.8 and 4.9):

$$(ef)^{-1}\bar{v}^{f+1} = a^{1/d}e^{-1/d}Y^{b/d}N^{-1}\bar{v}^{f/d}\ (1 - d/N)^{1/d}$$

$$e^{-d}f^{-d}\bar{v}^{fd+d} = ae^{-1}Y^{b}N^{-d}\bar{v}^{f}\ (1 - d/N)$$

$$\bar{v}^{d-f+fd} = ae^{d-1}f^{d}Y^{b}N^{-d}\ (1 - d/N)$$

$$(4.10) \quad \bar{v} = \{ae^{d-1}f^{d}Y^{b}N^{-d}\ (1 - d/N)\}^{1/[d-f(1-d)]}$$

Substituting (4.10) in 4.8):

$$(4.11)\quad \bar{Z} = (ef)^{-1}\{ae^{d-1}f^{d}Y^{b}N^{-d}\ (1 - d/N)\}^{(f+1)/[d-f(1-d]}$$

Substituting (4.10) and 4.11) in (4.4):

$$\bar{A} = [p(N.\bar{Z}) - c(\bar{v})].\bar{Z} - \bar{v}$$

$$= [aY^{b}N^{-d}\bar{Z}^{-d} - e\bar{v}^{-f}]\bar{Z} - \bar{v}$$

$$= [aY^{b}N^{-d}[(ef)^{-1}\bar{v}^{f+1}]^{-d} - e\bar{v}^{-f}].(ef)^{-1}\bar{v}^{f+1} - \bar{v}$$

$$= [aY^{b}N^{-d}(ef)^{d}\bar{v}^{-d(f+1)} - e\bar{v}^{-f}].(ef)^{-1}\bar{v}^{f+1} - \bar{v}$$

$$= aY^{b}N^{-d}(ef)^{d-1}\bar{v}^{-d(f+1)+(f+1)} - e(ef)^{-1}\bar{v}^{-f+1(f+1)} - \bar{v}$$

$$= aY^{b}N^{-d}(ef)^{d-1}\bar{v}^{1+f-df-d} - f^{-1}\bar{v} - \bar{v}$$

$$= aY^{b}N^{-d}(ef)^{d-1}\bar{v}^{1-[d-f+df]} - \bar{v}(1 + f^{-1})$$

$$= \bar{v}[aY^{b}N^{-d}(ef)^{d-1}\bar{v}^{-[d-f(1-d)]} - (1 + f^{-1})]$$

Substituting for $\bar{v}$ (from 4.10) inside square brackets:

$$\bar{A} = \bar{v}\ [aY^{b}N^{-d}(ef)^{d-1}\ [ae^{d-1}f^{d}Y^{b}N^{-d}\ (1 - d/N)]^{-1} - (1 + f^{-1})]$$

$$= \bar{v}\ [f\ (1 - d/N)]^{-1} - (1 + f^{-1})]$$

$$= \bar{v}\ [1/(f(1-d/N)) - 1 - 1/f]$$

$$= \bar{v}\ [1 - f(1-d/N) - (1-d)]/[f(1-d/N)]$$

$$= \bar{v}\ [- f + fd/N + d/N] / [f\ (1 - d/N)]$$

(4.12) $\bar{A} = \bar{v}[(-f.N + f.d + d)/(f(N - d))]$

From Dasgupta (1982, pp. 16-17):

$d < N \leqq d(1 + f)/f$

which implies:

(4.13) $(N - d) > 0$ and $-f.N + f.d + d \geqq 0$

Denote the term in square brackets in (4.12) as M; where, by (4.13):

$M \geqq 0$

From (4.12): $\partial\overline{A}/\partial Y = M.\ \partial\,\overline{V}/\partial Y$

From (4.10): $= M.[b/\{d-f(1-d)\}].Y^{[b/(d-f(1-d)-1]}.[ae^{d-1}f^{d}N^{-d}(1-d/N)]^{1/(d-f(1-d))}$

(4.14) $\partial\overline{A}/\partial Y = M.[d-f(1-d)]^{-1}.Y^{-1}.\overline{V}$

The term in square brackets is strictly positive (<u>cf</u>. Dasgupta, 1982, p. 17); hence (4.14) is non-negative.

Thus, for a firm in an industry of price-fixing firms characterized by symmetric equilibrium, where firms simultaneously determine output and research expenditures for process innovation, profitability is a non-decreasing function of output level, and thus price, in the final good industry. The process innovation R&D of this firm is also an increasing function of the level and price of final output.

(b) Product innovation in input producing industry

If embodied technological change is an increasing function of output price in the input-using industry, a model of the development of new embodied technologies is desirable which links the development of product innovations to other variables. This linkage is provided by an extension of the preceding model.

It is assumed that any yet-to-be-developed product innovation for Z may be modelled by equations (4.1)-(4.14), that a firm i devotes resources u_i to the search for new models j of input Z which have expected profitabilities A_{ij} (defined equivalently to equation 4.4) and that the probability of success of each model of this technology is a_{ij}. Assume that the expected number of product innovations discovered per period is $n_i = n_i(u_i)$, and is an increasing function of the level of research resources u_i. Ignoring time, total profitability (B_i) is:

$$(4.15) \quad B_i = \sum_{j=1}^{n_i} a_{ij}.A_{ij} - u_i$$

where it is assumed that the product innovations j can be ranked <u>ex ante</u> according to the sum of their expected profits $a_{ij}.A_{ij}$ and the research resources u_{ij} required for their discovery/development. The new innovations j can therefore be described by:

$$(4.16) \quad a_{in_i^*}.A_{in_i^*} - u_{in_i^*} > 0 \qquad \text{and} \qquad a_{in_i^*+1}.A_{in_i^*+1} - u_{in_i^*+1} < 0$$

and where the optimal level of search for new product models by firm i is:

$$(4.17) \quad u_i^* = \sum_{j=1}^{n_i^*} u_{ij}$$

i.e. where the last product innovation with positive net profitability is n_i^*.

But, assuming that the model in equations (4.1)-(4.14) may be used to model the search for new embodied technologies, there will be some increase in final output price - with accompanying increase in final output and hence increased demand for new embodied technology - for which:

$$(4.18) \quad a_{in_i^*+1} \cdot A^{**}_{in_i^*+1} - u_{in_i^*+1} > 0$$

where A^{**}_{ij} is the higher profitability for new embodied technology j with the increased demand for the final product. Hence the development of product innovations is an increasing function of final-product output prices, although this function is not necessarily monotonically increasing because of discontinuities in the process generating the number of product innovations.

Whether achieved by process or product innovation in the input producing industry, therefore, an increased demand for embodied technological change in purchased inputs resulting from increased final product prices can be hypothesized to result in the increased production of new embodied technologies in farm inputs.

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