Centre for Agricultural Strategy

Agricultural and food research – who benefits?

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1 Beneficiaries in the human food chain

David R Harvey

INTRODUCTION

For the purposes of this paper, the human food chain is centred on the farmer, seen as purchasing inputs from the agricultural supply sector, applying these to owned, hired or rented resources (land, labour, capital, including plant and equipment, breeding livestock, machinery and buildings). The products of this activity are subsequently sold to the manufacturing, processing, distribution and retailing (PDR) sectors for eventual delivery to consumers, either in their own homes or in hotels, restaurants and institutions (HRI trade). Research and development affects this chain and its participants through the introduction of new techniques and processes or the introduction of new products or inputs. The effects of R&D on the participants in the human food chain are likely to depend in part on the particular characteristics of the innovation, and thus are not subject to generalisation. However, the effects also depend critically on the circumstances and conditions surrounding the industry, on which this paper will concentrate.

To substantiate this assertion, consider the history of the agricultural and food sector. The technological development of the industry can be roughly divided into three major revolutions. The first of these was the agricultural revolution of the last century in which farmer-based innovations in equipment (Tull's seed drill) were associated with improvements in rotational practices (developed by Turnip Townshend and others) and the scientific application of mineral and organic fertilisers, based on the famous Broadbalk experiment at Rothamsted among others. The second, mechanical, revolution also began in the last century with the application of steam power to the farming industry and the development of associated machinery of which the threshing machine and ploughing engines are the obvious examples. However, this revolution did not really take off until the development of the internal combustion engine and the tractor in the first half of this century. The third, chemical, revolution began in earnest after WWII with the rapid expansion of artificial fertilisers and chemical herbicides and pesticides. While the first two predominantly affected the farm sector, the last also brought substantial changes in the PDR sector.

It is widely accepted that the agricultural revolution, and the associated improvements in farm productivity, enabled western economies to break free from their dependence on agriculture and to fuel the industrial revolution. Labour was released from the agricultural sector to work in the factories and warehouses of the rapidly growing industrial economy, while their food needs were met by an increasingly small fraction of the total working population. For a time, the agricultural sector prospered as a result, and the period between 1850 and 1875 is commonly referred to as the 'golden age' or the period of 'high farming'. However, as the farming revolution spread to the new world and steam rail transport and shipping routes became established, so the domestic market was undermined by lower priced imports, allowed in as a result of the repeal of the Corn Laws in 1846. The Great Agricultural Depression followed and lasted from 1875 to the turn of the century. Wheat prices fell by 50% and those for livestock products by 25% over this period. Arable land fell from 18.3 million acres in 1870 to 14.7 million in 1910, wheat from 3.5 to 1.8 million hectares. The agricultural population fell from 18% to 8% over the same period. In essence, then, the farmers gain from the technological advance of the agricultural revolution was relatively short-lived. As this revolution extended throughout the world, so the consumers and the rest of the economy began to reap the benefits at the expense of the farming sector. As we shall see in the next section, there is good reason to suppose that this is a general phenomenon under conditions of relatively free trade.

The mechanical revolution generated substantial changes within the farm sector, especially the replacement of animal (and some human) draught power by machines and the consequent release of arable land to grow food crops rather than feed for draught animals. It also allowed substantial savings in labour use and improvements in working conditions for the remaining agricultural labour force, while replacing draught animal services (blacksmithing, harness making) with their machinery counterparts. Productivity on both per person and per hectare bases improved as a result. Once again, the agricultural industry was able to release more resources to the rest of the economy without reducing output, though in this case there was little evidence of improved incomes and returns in agriculture. In addition, during the thirties there was little opportunity for alternative employment for those released from agriculture and a survey of farming during the depression would have found little evidence of benefits for agriculture from this phase of technological improvement. The 'Grapes of Wrath' stories from the US vividly illustrate the consequences of agricultural technological change in the western and southern plains for the indigenous agricultural populations, labourers and small farmers alike. On the other hand, it is doubtful if the UK could have withstood the blockades of WWII without the benefits of this revolution in farm techniques and practices.

The chemical revolution took off after WWII, again substantially improving the productivity of the farm sector though with little observable impact on aggregate farm incomes. The benefits of this revolution appeared in improving self-sufficiency for the UK, and associated improvements in the balance of payments (though here more arguable when more general consequences of agricultural expansion are considered). More recently, the costs of this expansion have become evident in the growing surpluses of farm products and the consequences of intensive agriculture for the natural and rural environment. While early adopters of the new technology were able to improve their personal circumstances for a time, these benefits evaporated as the industry at large adopted the new practices. The chemical revolution also permeated the PDR sector to an extent not seen under the previous revolutions, enabling the development of mass production and marketing systems geared to more reliable and less perishable products. The benefits of this progress depend to a large extent on value judgements about the quality of food and its safety, now being called increasingly into question. However, there is little doubt that the range of products and value for money have been improved as a result, largely to the advantage of the consumer.

Two major points emerge from this brief overview of the history of agricultural development. First, technological change, as the product of R&D undertaken in both the public and private sectors, generates substantial changes not only in agriculture but also in the rest of the economy. Assessing the benefits and costs of these changes is always problematical. What is the counter-factual situation? What criteria are we to use to evaluate change? How can changes to particular groups of people be measured? Are changes for one group directly comparable to those of another so that the net change for society can be obtained as the sum of partial effects? There are no unambiguous answers to these questions. Assessment under one framework may provide quite different answers to those under another. Second, the market, policy and social conditions surrounding the development of new technology heavily conditions both the way in which the new techniques are used and the distribution of gains and losses throughout society. What seems beneficial (and generally marketable and acceptable) at one time is not necessarily so at another. The chemical revolution provides a classic example of change in assessments of benefits.

Given these problems, are there any general conclusions which can be drawn about the possible beneficiaries in the human food chain? The next section turns to the economic analysis of technical change in an attempt to answer this question. In so doing, it necessarily abstracts from particular technologies and conditions. In other words, it will not be possible to answer completely the questions of whether the previous technical revolutions in the agricultural and food system have been 'good things' and, if so, for whom. However, economic analysis does offer some insights into the conditions under which certain groups in society might be expected to gain from technical change.

THE BASIC ECONOMICS OF TECHNOLOGICAL CHANGE

The principle device used by economists to describe and explain the workings of an economic system at the firm or industry level (as opposed to the level of a whole national economy) is the interaction of supply and demand. The supply of agricultural products is generated by the production processes used by the agricultural industry, which use up resources and inputs, effectively transforming these into useful outputs. These outputs in turn form the inputs used by the processing, distribution and retail (PDR) sectors of the food industry. The PDR sectors also use additional resources and inputs, such as labour, fuel, capital plant and equipment, to produce the food supply for the final consumer.

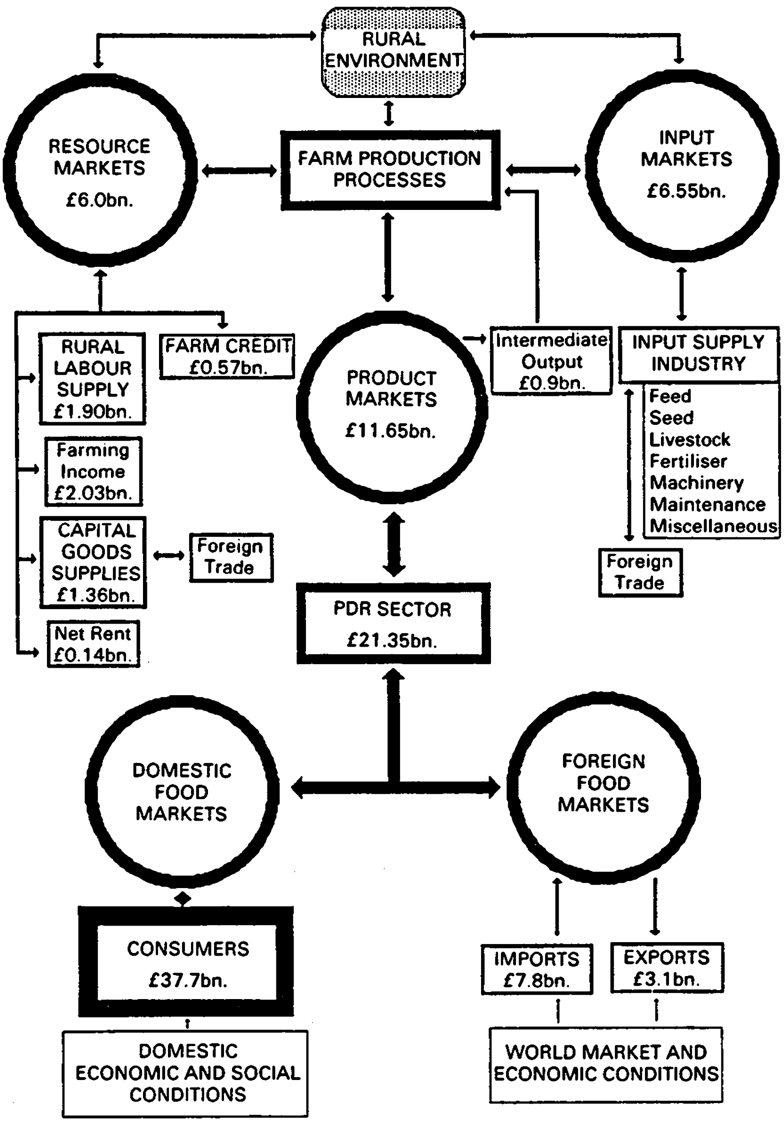
The demand for food comes from the final consumer, either at home or in restaurants etc, and is an expression of the needs and wants of people backed up by purchasing power (income and wealth). This final demand, in turn, generates demands by the PDR sectors for raw materials from the farm sector and for other inputs and resources from their owners and suppliers. Similarly, the demand for food facing the farm sector creates demands for agricultural inputs and resources used in the production of food. Thus the economic picture of the agri-food system is one of an inter-locking set of supplies and demands for the various products, inputs and resources which make up the system. The economics of the agri-food system consists, essentially, of analysing the balance between the supplies and the demands for the products, inputs and resources, and of identifying the changes in these balances as economic and other conditions change.

Technological change alters the 'rate of transformation' of inputs into outputs, or alters the characteristics of inputs and outputs to improve their attractiveness to the users and consumers. As technologies (including new products) are adopted, so supplies and demands will alter and the effects of the new technologies can be traced through the system.

While the representation of the Agricultural and Food industries as a production process is a useful way of describing the system, it is not a particularly useful way of analysing the behaviour of the system and its possible responses to technological change and to external influences. Figure 1 provides the alternative picture of the system which is more useful for economic analysis, based on the concept of markets.

An economist's concept of a market simply amounts to the trades which take place between firms and people with something to sell and others who wish to buy the same thing. In essence, the economic analysis of these

Figure 1
The Agricultural and Food Market System (1984)



Source of data: HMSO, Annual Review of Agriculture, 1986, Cmnd. 9708 trades consists of identifying the major determinants of the decisions to buy and sell. It is possible to estimate the relative importance of these determining factors, at the industry (ie aggregate or market level) by statistical analysis of data on market prices, quantities traded, and other data. Using these buying (demand) and selling (supply) relationships, it is then possible to construct a 'model' of the market, in which the supplies are matched to the demands by the adjustment of the quantities supplied and demanded and of the prices at which trades between buyers and sellers take place. Using such models it is possible to simulate the effects of changes in the determinants of the supply and demand decisions. Technological change (as the product of R&D) can be analysed through the way which it alters the supply conditions for products, and the demand conditions for agricultural inputs and food products.

The supply of goods and services (eg farm products) is determined by the profitability of the production process. The profitability, in turn, is a reflection of: (a) the price received for the product; (b) the costs per unit of the inputs needed to produce the product; (c) the alternative opportunities available for the resources used in the production of the output, and the cost and the amount of these resources available to the industry; (d) the physical relationship between the quantities of inputs and resources used and the quantity of product which they produce. Technological change, as the product of the R&D effort, affects the last of these factors – the physical relationship between inputs, resources and outputs.

In general, the higher the prices received for the product, the greater the profitability of the production process. Similarly, profitability will be improved by lower prices of inputs, or by greater quantities of output per unit of input. The more profitable the production of a particular product, the more people and firms will want to produce this product in preference to other products, so the greater will be the use of available resources to produce the output, and the greater will be the quantity supplied. An exactly similar logic applies in reverse, so that falling output prices reduce profitability which in turn encourages resources to find useful employment elsewhere, with the consequence that total output is likely to fall. Only in the event that farm resources have no options for alternative employment will falling prices not lead to a reduction in output from what would otherwise have been produced. Even in this case, profits can not usually be increased by increasing output in the face of falling output prices. Individual farmers may improve their income by taking over the resources (land) of their neighbours, but the total output of the industry will not be increased through this transfer. Cost/price squeezes may encourage farmers to adopt new techniques faster than they otherwise would, which will tend to increase output levels. However, the risks and costs of adopting new technology cannot be ignored, and are likely to be sufficient to prevent this response dominating the general tendency for output to fall as prices fall. Nevertheless output increases have been associated with falling real prices in the UK. This historical, time-based, association should not be confused with the underlying mechanisms at work in the market place. *Post hoc, ergo propter hoc* arguments are dangerously misleading in this case.

The demand for the product is taken as being determined by consumer choice. Consumers are treated as preferring lower prices to higher prices for the same 'good', and as seeking 'value for money' by choosing the cheapest alternative available to satisfy their needs. [It is recognised that 'consumers' needs' are an ill-defined concept, capturing the general tastes and preferences of people for goods and services, and undoubtedly influenced by the information available, the experience of consumers with alternatives, their health, education, social class, family size and structure, cultural influences, by the persuasive power of the suppliers and others through advertising, shelf-space, and so forth.]

In making their choices about which products to buy, consumers are limited by their available income (including their ability to borrow or run down savings). In general, the lower the price of a product, the more people will choose to buy. This is to be expected because, as the price of a good falls, so people will (a) tend to switch purchases from more expensive substitutes; (b) tend to buy more (and 'waste' more) of a product the lower its price; (c) tend to buy products which they did not previously purchase. Also, the higher the income levels, the more people will choose to buy; and the higher the prices of alternative goods which could satisfy the same or similar needs, the more of this product they will want to buy. In total, the more people there are to consume the product, the greater will be the total quantity that they wish to buy. The demand concept includes all of these effects on the total quantity that the consumers choose to buy.

The interaction of supply and demand occurs in a market, which includes all those who are prepared to produce and sell a given product and all those who wish to buy that product. Trades (exchanges of products for money) will happen between willing buyers and willing sellers, and the price for the product, as well as the quantity bought and sold, will be determined by the interaction of supply and demand. The price and the quantity bought and sold will tend to adjust until the price that the consumers are willing to pay for an additional unit is just enough to persuade the producers to sell that additional unit to them. This is commonly and conveniently represented in diagrammatic form (Figure 2). This emphasis on the marginal valuation of commodities (the value to the consumer or user of the last unit purchased) and the marginal cost (the cost of producing the last unit sold) is a central concept in economic analysis.

In Figure 2, all of the determinants of quantities supplied (S) and demanded (D) except price are treated as being held constant, so that it is only the effects of different prices on quantities supplied and demanded which are shown by the curves in the diagram. As outlined above, the diagram shows that quantities supplied will tend to increase as the price is increased, while the quantities demanded will tend to decrease as the price increases. Given their relationships, there is only one price at which the quantity consumers are willing to buy is equal to the quantity that producers are willing to sell. The market mechanism of willing buyers trading with willing sellers is thus expected to determine the price of the product and the quantity bought and sold, and thus the total expenditure on (and the total receipts from) the product – as price times quantity traded. A market is said to be in equilibrium when this price and quantity is achieved (in the sense that neither price nor quantity traded would be expected to change unless the other determinants of supply and demand alter).

Using this conceptual apparatus, economists trace the effects of changes in market conditions on producers and consumers. For example, if the technology of production is improved, then this may be represented by a shift of the supply curve downwards and to the right, (from S to S^1 in Figure 3) since the improved technology allows producers to supply the same quantity at a lower price (cost-reducing – from po to pi), or to supply more at the same price (output increasing – from qo to qi). Immediately, the distinction between cost-reducing and output-increasing technological change becomes a matter of market conditions, determined by the responses of both producers and consumers, rather than a characteristic of the technological change itself. Given a downward sloping demand curve, the effects of this technological improvement is to increase the quantity produced and sold (from qo to qe) and also to reduce the price of that product (other things being treated as unchanged) – from po to pe.

Figure 2

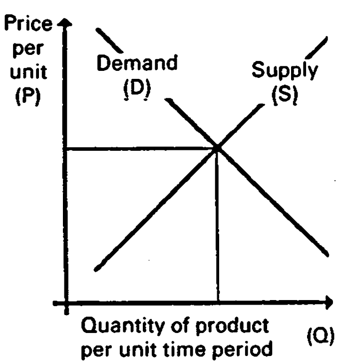
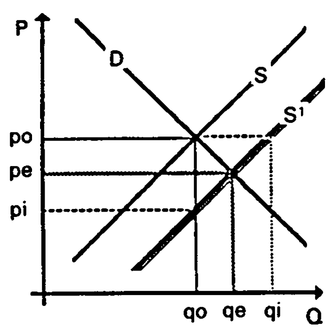


Figure 3



For convenience, all of the illustrations of this analytical approach picture supply and demand curves as linear, though in both theoretical derivation and practical estimation these relationships seldom turn out so. In addition, the diagrammatic representation of technological change is shown in Figure 3 as a parallel shift of the supply curve. In practice, the characteristics of the invention (discovery) of a new technique or the use of a new input, and the subsequent adoption process among the producers, are both likely to influence the way in which the supply curve shifts.

The supply curve represents the distribution of the marginal unit costs of producing the commodity. One of the major reasons for supposing that supply curves slope upwards is that the costs of producing the first few units of a commodity are likely to be lower than the costs of producing subsequent units, since the most appropriate (efficient) resources and inputs will be devoted to production before their less efficient counterparts. Marginal production is thus defined as the highest cost production, which is not uniquely associated with particular 'marginal' farmers or marginal land. For instance, the experience with milk quotas shows that the final few litres per cow and per dairy farm were costing a lot more to produce than the bulk of production, almost regardless of the circumstances of the farm, since the average costs of producing milk have fallen since the introduction of quotas. In this case, at least, the production represented by the upper part of the supply curve is, apparently, distributed over most dairy farms, rather than being restricted to the 'marginal' or supposedly inefficient farms. Similarly with cereals, it is both logical to suppose, and is also supported by the evidence, that the final tonne produced even on the 'best' cereal farms is costing almost as much to produce as is being earned by its sale, while the first tonnes produced are relatively cheap to grow, once the decision to grow cereals at all has been made.

The effect of additional quantities supplied on total receipts and expenditures on the product (p times q in these diagrams) depends on the slope of the demand curve. If the demand curve is flat[1] –(the demand curve is relatively *elastic*), then a technological change will tend to increase output and sales rather more than the associated reduction in price, and expenditure on the product (and thus receipts earned from their sale) will tend to increase as a result (Figure 4). If, on the other hand, demand is steep (*inelastic*), then price will tend to fall by more than sales increase, as a result of the technological change, and receipts and expenditure will tend to fall (Figure 5). In developed economies, with well-fed people, the demand for farm products tends to be inelastic (both with respect to price and to income), so the usual economic presumption is that technological change benefits the consumer (or at least the farm product processor and user) rather than the producers. It is not generally possible to charge consumers and users directly for the benefit they get from improvements in agricultural technology, since the consequent reductions in the price of the product are uniformly available to all consumers regardless of whether they pay for the

R&D or not. This means that private businesses cannot recoup the costs of R&D from the market place and the R&D which produces the technological improvement must be paid for from public funds if it is to be provided at all.

Figure 4

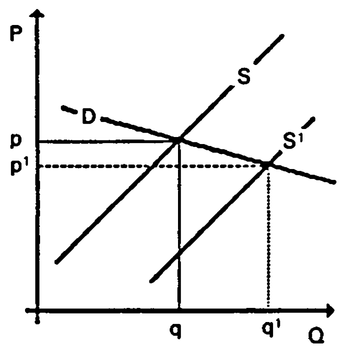
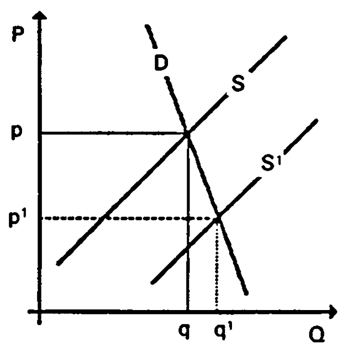


Figure 5



The effect of a new technology on the amount and costs of production is not, however, instantaneous. There are lags in adoption, with some farmers adopting a new technique or input sooner than others. The supply curve, representing the sum of all farms supply responses, will tend to shift to the right over time as more and more farmers adopt the new technique. During the early stages of the adoption process, early innovators will benefit because their costs per unit output will be reduced by the use of the new technology (otherwise it would not be adopted), but the price of the product will not have been reduced much because the industry's supply curve will not have shifted very much. Hence, early adopters might be expected to be prepared to pay something towards the provision of new technology, and would also be expected to devote some of their own resources to inventions and new practices themselves. However, these early adopters and innovators will not generally invest in as much R&D (either on their own account or on contract) as is warranted by the eventual total benefits to consumers, arising from the increased quantities bought and their lower price, and also by the release of resources from agriculture to provide other non-agricultural goods and services.

Markets for different products are linked through both the supply and the demand side. On the supply side, for instance, a reduction in cereal prices relative to other prices would be expected to encourage at least some farmers to switch land and other resources away from cereal production to other products (oilseeds or livestock). The switch to livestock would also be encouraged because of the relative fall in feed costs associated with the fall in cereal prices. In the terms of the above analysis, changes in price of one product will shift the supply curves of other produces – a fall in cereal prices shifting the supply curve for pigs and poultry downwards and to the right since feed costs would be reduced. Similarly on the demand side, where for instance an increase in the price of beef relative to the prices of other meats would be expected to result in an increase in the demand for other meats, as consumers choose to buy pork instead of the dearer beef. In addition, there are other factors than prices which have a substantial influence on the demands and supplies of the products in the food and agricultural system, and in an applied version of this framework these are likely to be of overwhelming importance. Practical use of this framework involves mathematical relationships on the computer, involving many more of the variables which affect supply and demand, and the statistical testing and estimation of the hypothesised relationships using data on prices, costs, incomes, quantities, and so on.

This basic analysis is sufficient to provide an explanation of the initial consequences of the agricultural revolution mentioned in the introduction. The revolution shifted agricultural supply curves downwards and to the right, which would have been expected to lead to falling product prices. However, the industrial revolution elsewhere in the economy was associated with an increasing demand for food, shifting the demand curve upwards and to the right, thus tending to increase prices. The net result was that product prices did not fall markedly and the benefits of the revolution were largely retained by the farm sector as increased profits (see below).

This analysis, however, ignores the possibility of importing farm products from abroad, or exporting these products to world markets. The possibilities of trade can be most simply represented by supposing that the country is sufficiently small in relation to the total world production and consumption that changes in its imports and exports have no discernible effect on world prices. (This assumption can be relaxed in practical applications of this framework). In economic terms, this simplification means that there is a perfectly elastic supply of imports at the going world price for the product, (or, in the case of an exporting country, that the demand for exports is perfectly elastic at the world price). This situation is represented in Figure 6. The world price (pw) is, in turn, determined in a world market. A shift in the domestic supply curve, from S to S^1, reflecting technological change, means that domestic suppliers can supply a larger share of the home market than before. The change thus benefits producers but not consumers (whose prices are not changed) and also benefits the balance of trade, and thus the economy, as was largely the case under the initial flowering of the chemical revolution.

Figure 6

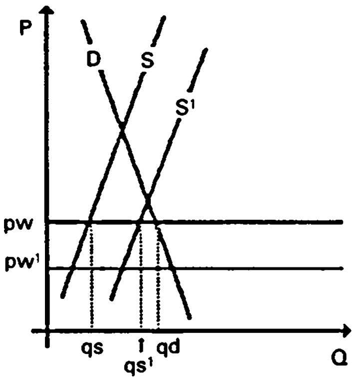
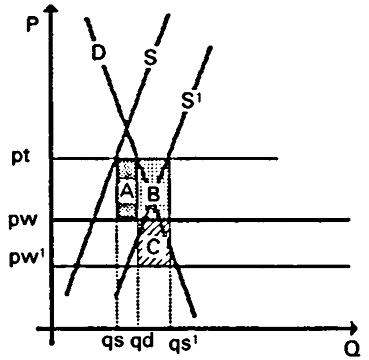


Figure 7



However, if the technological change can also be adopted abroad, then world supply curves shift to the right and world prices would fall as a result (other things unchanged) to pw^1, and ultimately benefit consumers everywhere, including those at home, as eventually happened as a consequence of both the agricultural and chemical revolutions (and indeed the mechanical revolutions, though here the effects are masked by the world-wide consequences of the depression and WWII). The implication is that internationally relevant technological change should be paid for (and organised) on an international rather than national basis. A further implication of this analysis is that the 'regional specificity' of technological change is an important component of the mix of characteristics which determine the effects of the change, and hence determine the potential costs and benefits associated with its adoption.

In practice, however, countries are seldom content to let 'naked' market forces determine the prices (and thus the returns) of agricultural products. They implement policies (eg the CAP) to suppport market prices (eg at pt in Figure 7). In its simplest terms, the market price support policy of the CAP can be represented as providing a perfectly elastic demand curve at the support price for the agricultural industry. This support price is maintained by imposing taxes (levies) on supplies imported from the rest of the world, which increases the price that must be paid by domestic consumers from the world price by the amount of the import tax per unit. The total revenue raised by the imposition of the import tax is represented by the shaded area A in Figure 7.

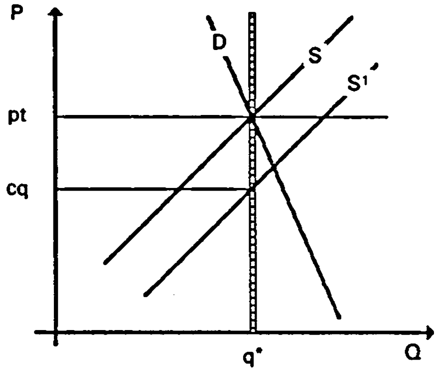
In the case of a commodity which is produced in surplus to domestic requirements, the support policy provides subsidies (refunds) for exports to the rest of the world. Under these circumstances, a shift in the supply curve resulting from technological change means: (a) that producers benefit and taxpayers lose (lower import tax receipts or greater export subsidies – shaded area B in Figure 7); and (b) that surpluses increase, unless support prices are reduced as new technology is adopted. This illustrates the problem of the CAP, namely that early adopters could cope with the price reductions which would be necessary to avoid the build up of surpluses, but late adopters (small farmers?) could not, so that politicians are unwilling to accept the necessary price reductions.

The clear implication of this analysis is that it is not technological change (and the R&D which produces it) which is responsible for the surpluses, but the failure of the market price support policy to respond to the new technology which produces the surpluses and the associated growth in budgetary costs. Further implications are: that producers (as the beneficiaries of technological change) could be charged for the provision of R&D on their behalf; and also that, from the point of view of society as a whole, the appropriate prices at which to value the effects of the new technology are the world prices rather than the domestic support prices. (However, there are additional complications associated with the CAP and the funding of the EC budget which may alter this last implication in practice for a single member state like the UK). If the technological change is adopted elsewhere in the world under a market support policy (as depicted in Figure 7), then the resulting fall in the world price – to pw^1 – further increases the cost to the taxpayer of the export subsidies, by shaded area C in Figure 7.

A further application of this framework illustrates the effect of the market and policy conditions on the adoption of technological change as a 'cost-reducing' or 'output-increasing' change. In the situation of unlimited guarantees, as represented above, all technological change will have the effect of increasing output rather than reducing prices (and thus costs). However, the milk sector is now controlled by dairy quotas, limiting the amount that can be produced. In effect, this means that the EC is only prepared to support prices for an absolutely limited quantity of production, which can be represented as a perfectly inelastic demand curve (ie vertical) for milk at the total quota level. Under these conditions, technological change will now have the effect of reducing the costs of current (quota restricted) output rather than resulting in increased quantities supplied as illustrated in Figure 8.

It would, by the same token, allow the milk support price to be reduced to the advantage of the consumer and user of milk. The effect of technological change which reduces the cost of dairy production in the face of production quotas illustrates an important general point. Those farmers who adopt the new technology will find that their milk quotas are now worth more than before the technological change, and will be willing and able to afford to pay more for additional quota. If there is some sort of market for milk quotas, then these early adopters will bid quota away from the 'laggards', and bid up the value of the quota. Since, to the individual farmer, the cost of the quota

Figure 8



The effect of technological change in the presence of quota limits on production is to reduce the effective costs of production from pt to cq per unit, rather than to increase output. (The difference between pt and cq will be the value of a unit of quota, given a total quota of q* units)

(or the price which could be obtained for the quota if it were to be sold) represents a genuine part of the costs of production, the effect of the improved technology is to reduce some costs while increasing others. In this case the ultimate beneficiaries are the owners of the quotas, since the value of their assets is increased by the technological change. In this case, these owners are likely to be synonymous with the present dairy farmers, but new entrants to the dairy industry will not benefit financially from the new technology, whose benefit will be reflected in the increased price new entrants have to pay for quota.

An exactly similar analysis applies to those products which are not controlled by production quotas, except that the assets which attract the benefit of the new technology through higher values are likely to be the land, capital and managerial labour currently employed in the industry. Put another way, the reduction in the costs of production and the associated increase in profitability following from an improved technology will tend to drive the price of agricultural land and capital equipment up, as more people try to take advantage of the improved profits and attempt to buy the necessary land and equipment. Thus rapid technological improvement is not likely to be reflected in improved earnings in the industry, but only in increased values of the assets (resources) used in the industry. The evidence shows that this is exactly what has occurred in UK agriculture, with land prices, machinery and capital costs increasing in almost locked step with improvements in productivity, with little if any effect on residual farm incomes.

Representation of gains and losses

Underlying the economic analysis of technological change outlined above are notions of consumer and producer welfare measured in terms of willingness to pay or be compensated for changes in economic circumstances. Consider Figure 9, which shows a supply curve and the output level

Qs1 associated with price Ps1. The supply curve can also be interpreted as showing that price which must be paid in order to call forth particular quantities, in other words, the price which will just provide sufficient returns for the inputs and factors employed to be able and willing to produce that particular quantity. In the language of economics, the supply curve reflects the marginal cost of producing each quantity. Thus, the area beneath the supply curve and the current price represents the total cost of producing that level of output[2]: the sum of the additional cost incurred in producing each successive unit of output. Since the total receipts received from sale of the product is given by the rectangle (Ps1*Qs1 in this case), while the costs of production are given by the area beneath the supply curve, the area above the supply curve and beneath the price line is termed 'producers' surplus' (shaded area in the figure).

What happens to this surplus? In fact, as pointed out by Mishan among others, it is not surplus at all, it represents the return to fixed factors of production and is the contribution to the fixed costs[3] incurred in producing anything at all. In that sense, it is more accurately referred to as 'quasi-rent' – quasi since if these returns are not sufficient to match the earnings these factors (land, labour, capital investment and management skills) could command in some alternative occupation, then it is to be expected that these factors will leave the industry (in this case the production of this product) for alternative occupations. Conversely, if the producers surplus is increased (see below) then the rents earned by the fixed factors is increased, attracting more factors into the industry and raising the returns of those already in the industry.

Figure 9

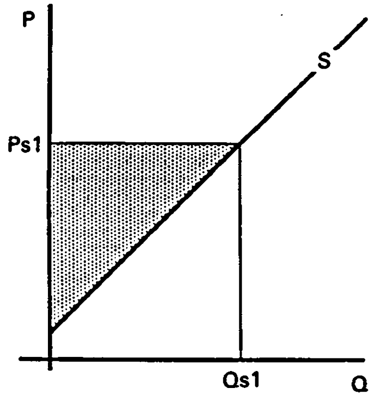
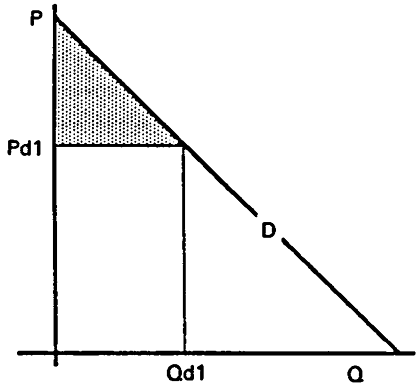


Figure 10



The demand side of the story is told in Figure 10. The demand curve may be interpreted as the price which consumers are willing to pay for a particular quantity (Pd1 for Qd1 in the figure). Under this interpretation, consumers would be willing to pay more for a reduced quantity. The total amount consumers would be willing to pay for Qd1 is, therefore, the total area to the left of Qd1 and beneath the demand curve. But they only actually pay the rectangle Pd1*Qd1. The additional amount, (the shaded triangle in the figure) is termed 'consumers' surplus' – the additional amount they would be prepared to pay over and above the actual cost of quantity Qd1. Under this interpretation, the consumers' surplus becomes a monetary measure of 'net satisfaction' from consumption[4], and is widely regarded as a genuine measure of net gain.

The concepts can be used to measure gains and losses from changes in market or policy intervention conditions, including those following technological change. In Figure 11, technological change is associated with unchanged producer prices for output, and the producers' surplus gain is identified as the shaded area. It becomes apparent that estimates of the gain depend crucially on the effect of the technological change on the supply (and thus cost) structure of the industry. A parallel shift of the supply curve would generate greater gains than a convergent or divergent shift of the same average magnitude. As noted above, these gains are expected to show up in the earnings of the fixed factors in agriculture, though the distribution of these gains amongst the fixed factors will depend on both the nature of the technological innovation and on the supply conditions for the factors, in other words, the earnings these factors could command in other occupations. Thus, the agricultural revolution effectively increased land productivity, and therefore labour and capital productivity, potentially increasing rents, return on capital and wages in the sector. However, the emerging industrial revolution was also raising wages and returns on capital and wages in the sector. However, the emerging industrial revolution was also raising wages and returns on capital in the rest of the economy, leading to a reduction in the labour force in agriculture, though probably not in capital investment, though data on the latter are not available. Again, as already noted, product prices eventually declined as the agricultural revolution became more widely dissipated, leading towards the situation represented in Figure 12.

Here, producers' surplus falls as prices fall, offsetting the gains made from the adoption of the new technology. Overall returns to fixed factors might not change in these circumstances, though this average result need not apply to each factor separately. The mechanical revolution increased the productivity of capital employed, leading to a substitution of capital for both labour and livestock. Only through release of labour from the sector were earnings of the remainder able to keep pace with those in the rest of the economy. It is noticeable that farm sizes remained fairly constant or even fell in the century before WWII, and only began to increase in the post WWII era,

Figure 11

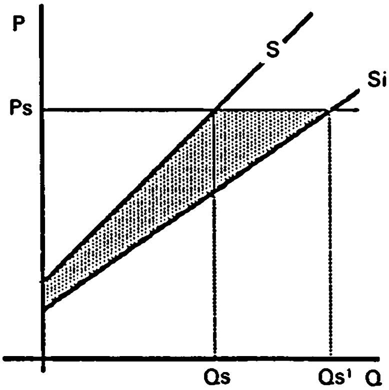
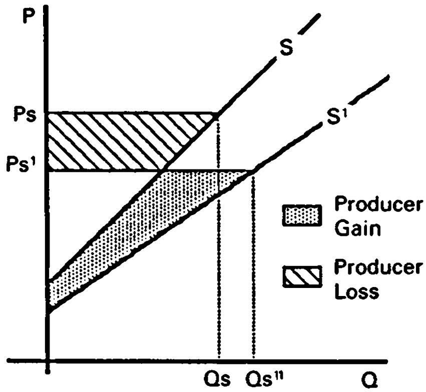


Figure 12



as the second phase of the mechanical revolution got underway, in which the potential economies of size both of machines and farms began to be exploited in conjunction with the chemical revolution. One may hypothesise that earnings outside agriculture during the pre-war period were not sufficient to attract farmers (or their offspring) away from agriculture, although the hired labour force continued to decline.

The 'supply side' technological developments may lead to a situation in the farm sector which has been described as the technological treadmill. Improvements in the productivity of certain inputs (chemicals, fertilisers, machinery etc) lead to both cost reductions and output increases as these improvements are adopted on the farm. As this occurs, so there is pressure on total farm returns as market prices for the products fall. Only those farmers who adopt the new technology can survive this pressure, others are forced out of the industry. The farmer is caught on the technological treadmill, innovating and adopting new practices, simply to survive, without improving their economic circumstances at all. From society's point of view, this characteristic may not matter much, since the benefits of the technological improvement can be passed on to the consumers (or, in the case of supported markets and the appropriate adjustments of support prices, to the taxpayers).

Sometimes, however, there are important side-effects of the technological uptake at the farm level (eg nitrate build up in ground water; chemical residues in plant and animal products and the soil; increased field sizes, monocultures and hedgerow removal associated with the adoption of more commercially efficient machinery, and so on). The full consequences of these effects on society are not dealt with by the free market mechanism. There is no market in which people can 'buy' better landscapes, cleaner ground water supplies, or generally 'chemical-free' food stuffs – although there are opportunities for some markets to develop in some of these areas. In the case where no free market for the 'goods' and 'bads' associated with production processes exists, the economist refers to these 'goods' and 'bads' as externalities (since they are produced and consumed, or suffered, externally to the market place). R&D devoted to the reduction or elimination of 'bads' and the increased production of 'goods' will not be provided by the private sector, since there is no market in which private firms can recoup the costs of their R&D. If this research is to be done, it will have to be done with public funding.

Extensions – upstream and downstream industries

A similar analysis can be applied to farmers' demand for inputs. In this case, the demand for the inputs depends on the amount of the product which the farmer intends to produce, which in turn depends on the profitability of product. In other words, the demand for inputs is said to be 'derived' from the demand for the product. On the supply side of the input markets, however, the simple version of the supply curve needs to be modified to recognise that, for example, fertiliser and chemical manufacturers are 'concentrated' (with very few major firms supplying the market). Under these circumstances, the firms are able to influence the prices charged for the inputs, and do, in fact, set their own prices, unlike wheat farmers. Having set the price, however, the logic of the market place dictates that they have to be satisfied with the resulting level of sales that they can make at these prices. Nevertheless, since these firms can set their prices, they could capture the benefits of technical change for themselves, rather than passing the benefits on to the producer in the form of lower prices (or the equivalent of a better input at the same price). Furthermore, since they are large firms, they can afford to invest in their own R&D, in the sense that the substantial costs associated with this activity can be defrayed over a large turnover.

The extent to which these firms can actually capture all of the benefits of new technology depends on competition they face from other firms in the same industry (or those producing alternative inputs or employing alternative methods to produce the same output). In practice, the competition between these firms to retain and increase their share of the market means that they will be forced to pass on at least some of the benefits of their research to the purchaser of those inputs (ie the farmer). Hence there is a logical presumption that these industries will finance their own R&D, and that a major reason for this investment from the firm's point of view is to compete more effectively for market share. Furthermore, they are likely to try and spread the costs of research over as large a market as possible.

The implication is that there will be a tendency for rapid technological development in the input sector to be associated with an increasing concentration of the production of the inputs among fewer firms, and also that these firms will tend to operate as international or multinational companies so as to increase the size of their markets. Their R&D divisions are the key to their commercial survival – the better they are in competition with their rivals, the bigger their market share and the more resources they can then afford to devote to the research effort to maintain their share. In comparison, the fortunes of the agricultural sector which they serve may exert relatively little impact on their efforts, and indeed may even work in what seems to be a perverse direction, since the greater the economic pressure on the agricultural industry, the slower will be the overall growth in the input markets and the greater will be the competition among the input suppliers to retain and increase their market shares. In contrast, a buoyant agricultural industry, expanding its demands for inputs, affords the input suppliers the scope, to say no more, of retaining more of the benefits of their previous research effort for themselves.

A further implication of this analysis is that there is likely to be a substantial duplication of research effort among the competing firms (eg the chemical and drug companies) at some additional cost to the user of the products in terms of the costs of the inputs (including the costs of the research effort). Private competition in the research activity can, therefore, provide a strong incentive to 'productive research' but may also result in considerable waste. The balance of the costs and benefits to the economy as a whole of these two tendencies compared with some possible alternatives would make an interesting study. In turn, the results may have considerable implications for the appropriate organisation of private and public research, in particular for the place of privately funded research in single, quasi-public, research institutions as a possible way of resolving the paradox of private competitive funding of R&D – the market-related orientation of the research effort and the tendency for expensive duplication.

The connection between the markets for the 'raw' farm products and the final retail markets for food shows that the demand for food (and other) products at the farm gate is also a derived demand (as with the demand for agricultural inputs), in this case derived from the final demand for food products and conditioned by the technology and economics of the food manufacturing, processing, distribution and retail sector. This PDR sector, like the input industries, is characterised by significant concentration and market power, at least in some parts, and one would expect a considerable amount of privately funded R&D as a result. However, it is also characterised by a relatively static final demand for food products, so that the competition is centred on the maintenance of market shares, either through the differentiation of products and associated 'brand-loyalty', or through the reduction of the costs of the whole PDR process. Technological change has an important role in both of these alternatives, in producing 'new' food products which are more attractive to the consumer, and in adopting new processes which reduce the costs (or improve the quality/eliminate waste) of delivering the products through the PDR chain to the consumer.

Again, as with the input industries, private R&D will tend to be devoted to innovations which can be captured by the company undertaking the research, so that the economic advantages can be expected to earn a sufficient private return to pay for the R&D. The principle characteristics of these R&D projects are likely to be:

(i) that the 'payoff' can be made specific to the firm in some way, eg through patents or through specific application to a production process or technology unique to the firm;

(ii) that the 'payoff' can be earned relatively quickly, so as to earn a satisfactory rate of return in the face of commercial interest rates on the R&D investment and the inevitable uncertainty of the R&D activity.

As a result, it is unlikely that privately funded research in either the input or the PDR sectors will be concerned with long-term basic research, or with research devoted to generally applicable innovations which can be adopted quickly and inexpensively throughout the industry. Only in the case of co-operatively funded research will these types of projects be undertaken by the private sector (as through the Research Associations, for instance).

There is a further inference that can be drawn from this analysis for the development and organisation of R&D directed towards the food (PDR) sector. Since this sector provides the link between the final consumer demand and the demand for products at the farm gate, developments in the PDR sector are likely to have repercussions in the farm sector, both for the quantities and the qualities of the raw products demanded at the farm gate. The benefits of improvements in the PDR sector could, at least in principle, filter back up the food chain to the input suppliers and the owners of the basic resources employed in the production of the raw materials, as well as downstream to the final consumer. These links introduce considerable complications to the elaboration of the economic (as opposed to the commercial and financial) costs and benefits of the technological change.

SUMMARY AND CONCLUSIONS

This introduction to economic analysis and the economic consequences of technical change show that the economic appraisal of technological change is likely to be complicated. The adoption of any technological improvement depends on the economic circumstances of the businesses and individuals concerned, and thus on the economic circumstances of the industry. Economics is thus important in determining which parts of the additions to the knowledge pool arising from R&D are actually exploited in the commercial world. The economic analysis outlined in this paper deals with, those R&D results which are actually used in the commercial world as 'innovations', though this is not to deny that there is value to *all* R&D results, even negative results, in the sense that future research can only build on the current state of knowledge, and that state is improved to at least some extent by any and all research.

Perhaps the most important message to come from the outline analysis of this paper is the relationship between prices and costs. It might seem self-evident that an innovation which reduces the costs (ie the resources and inputs) needed for production is a good thing for farmers. However, the reduction in production costs will itself lead to economic reactions – namely for output to increase and for product prices to fall, or for the competition for agricultural resources, especially land, to increase and for their values to rise. The net result of an innovation which reduces costs (or increases output from the same inputs) is to set in motion a chain of economic reactions which adjust other prices and costs to take account of the innovation. In particular, if profits are improved by an innovation then there will be incentive for expansion and for new people to come into the industry which will drive up costs and use more inputs and resources. Likewise, if output is increased, then there will be pressure on market prices so as to balance the market with greater output levels. As product prices fall, so profits are reduced towards their initial level. It is often a serious mistake to assume that R&D directed towards agriculture necessarily benefits the practising farmer. The economic system serves to dissipate the benefits of the innovation among a wide variety of people, and the distribution of the benefits cannot be guaranteed to be uniform or 'fair'.

The consequences of the innovation for output increases or for cost reductions depends on the market conditions facing the industry, and will differ between the early adopters and the bulk of the industry, so that it is not possible to generalise from the particular circumstances of a single business to the consequences for the industry as a whole. In a purely domestic market, with no government intervention, it seems likely that the consumer will benefit most from technological innovation; while in an international market the consequences depend on the applicability of the innovation. If the innovation can be adopted around the world, then the consumers again will be the ultimate beneficiaries as and when the innovation is adopted. If, however, the change is specific to this country, then the national benefits are preserved within the country and fall mainly to the domestic producers and to the balance of agricultural trade. In the case of a government-supported industry, where the support is open-ended and not limited to a specific quantity of production, then the benefits either accrue to the producers (if the support price is maintained) or to the taxpayers and consumers (if the support price is reduced according to the cost reduction potential of the innovation). If the government support is limited to a specific quantity, then the benefits of an innovation accrue to those who own the right to produce the limited quantity, or to the taxpayers and consumers if the support price is reduced. These possibilities are summarised in Figure 13, which gives a clear indication of the care needed in the economic appraisal of the effects of technological change, if nothing else!

The pattern of adoption among producers will also affect the economic consequences of the innovation. Innovations which reduce the costs of the marginal (highest additional cost) output by more than the intermediate output, are likely to have more dramatic effects on output and cost than if the innovation is targeted towards the least cost production (ie that output which would continue to be produced even at much lower product prices than now). In the latter case, the major effects will be on the values of the assets, especially land, used in agriculture.

The way in which the innovation is made available to the end-user is also important. If the change is 'embodied' in a new machine, or a patentable product, or marketed through a licensing system which allows the supplier of the new technology to charge for the benefits of using the innovation, then the cost savings by the users of adoptions will be smaller than otherwise, and there will be a slower and lower rate of adoption and less impact on product and input markets. However, the degree of competition in the supplying market will also influence the extent to which the suppliers can capture the benefits of the change for themselves, and thus prevent the full effects of the change showing through to the product and input markets. The greater the changes of the benefits of the new technology being captured by the supplying organisation, the more likely it is that the underlying research will be done with private funds. The most persuasive case for the public funding of R&D is that the benefits will be diffused among a wide variety of people with no possibility of charging each and every one separately for their benefits.

The case for public funding is further strengthened for those effects and innovations which reduce bad side-effects of production practices and promote the good side-effects (externalities). The commercial market place cannot deal with these externalities, and the only way in which their existence can be coped with is through public intervention, including the provision of R&D. In the final analysis, however, this discussion has focused on the products of R&D which are actually used by the industry. This is not the same thing as the total output of the R&D service, which is to provide a technological pool of new alternatives and opportunities which might or might not be relevant to particular market, policy or social conditions. The way in which the technological pool is fished in depends critically on these conditions, as does the distribution of benefits. Thus any conclusions about who should pay for research based on some particular identification of beneficiaries must assume that present market, social and policy conditions will persist. The real danger of this approach is that the very adoption of new technology will itself alter these conditions, and further is likely to condition the uptake of future technologies. Particularly at the present time, in which all these conditions are subject to profound pressure for change, augmented by the threat of substantial change in underlying environmental conditions, prediction of adoption patterns of new technologies become difficult if not impossible, *a fortiori* for the identification of future beneficiaries.

Figure 13
Effects of technological innovation on a competitive market

Policy & Mkt Conds / Effects on:	Closed & Free Domestic Market		Small Country Trader – Innovation:		Government Supported Market	
	Demand Inelastic	Demand Elastic	Regionally Specific	Generic	Support Open Ended	Support Limited
Output	+	+ + +	+ + +	+	+ + +	nc
Price	– – –	–	nc	– –	nc	nc[3]
Expenditure & Receipts	– –	+ +	+ + +[4]	+	+ + + (Rec)[3] nc (Exc)[3]	nc[3]
Consumers & Users	+ + +	+	nc	+	nc	nc
Producers[5]	+ / –	+ +	+ + +	+ / –	+ + +	+ + +
Taxpayers	na	na	na	na	– – –[3]	nc[3]
Balance of Trade	na	na	+ +	+ / –	+ + +	nc
Resource & Input Use	–	+ +	+ +	+ / –	+ + +	– – –

Notes:

1 na means 'not applicable'
2 nc means 'no change'
3 The adoption of an innovation allows for the possibility for support price reductions. If these occur, then prices in the market fall, and expenditure and receipts would also fall, and in the case of limited support, taxpayers' expenditure would also fall. In the case of open ended support, taxpayers' expenditure would not increase by as much.
4 On Domestic production only, consumers' expenditure in total will not change.
5 Producers' effects are an indication only of the 'first round' effects of the change. As profits are improved, so economic forces will be set in motion which will dissipate the benefits among the owners of the factors and resources used in the production process.

The analysis underlying this matrix assumes that the innovation is passed on to the producer at cost, rather than priced so as to capture some or all of the potential benefit for the supplier. If the innovation is priced so as to capture all of the benefit for the supplier, then the product supply curves would not shift and none of these effects would occur.

NOTES

[1] In fact, the effect is more accurately measured by the 'proportional slope' of the demand curve – the % change in the quantity demanded per 1% change in price – termed the (price) elasticity of demand. The greater the proportional effect on the quantity demanded of a change in price the more (price) elastic demand is said to be, and vice versa. [Similar notions of elasticity are applied to the relationships between demand and income; demand and the prices of other products; and supply, prices and costs].

[2] Since the marginal cost is, by definition, the first derivative of the total cost curve with respect to quantity, the integral of the marginal cost curve (the supply curve) yields total cost, aside that is from the constant of integration, which is interpreted as the fixed costs, returned to below.

[3] Where fixed costs, by definition, do not vary as output levels vary but remain constant for any non-zero level of production.

[4] Which may, of course, become infinite if the demand curve never intersects the vertical axis!