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Induced Innovation Theory and Agricultural Development in LDCs: An Appraisal

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Induced Innovation Theory and Agricultural Development in LDCs[1]

An Appraisal

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(1) INTRODUCTION

Sir John Hicks original notion of "induced invention" is over fifty years old and Hayami and Ruttan's application of the inducement concept to agricultural development is rapidly approaching its twentieth anniversary. This paper tries to evaluate both the original inducement hypothesis and the broader development model. Particular attention is then paid to empirical investigations of the induced innovation hypothesis.

(2) HISTORY OF THE MICRO-ECONOMIC APPROACH TO ENDOGENOUS TECHNICAL CHANGE

It is now 56 years since Sir John Hicks' (Theory of Wages (1932)) introduced the elasticity of substitution and the idea of "induced inventions", which endogenised the factor-saving bias of technological change at the level of the firm. Nor are the two concepts clearly separated, since in the original exposition Hicks writes,

"The real reason for the predominance of labour-saving inventions is surely that which was hinted at in our discussion of substitution. A change in the relative prices of the factors of production is in itself a spur to invention, and to invention of a particular kind - directed to economising the use of a factor which has become relatively more expensive. The general tendency to a more rapid increase of capital than labour which has marked European history during the last few centuries has naturally provided a stimulus to labour-saving invention." (p124).

The last sentence is included to show that capital is being treated along with labour as if it were a primary, rather than a produced means of production. This lack of distinction between reproducible and non-reproducible factors, was picked up by Gerald Shove in his 1933 review;

"If capital means concrete capital goods, these are themselves the product of labour, so that it would seem, the rise in wages must cause a proportionate rise in their costs of production" (reprinted,

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[1]. Helpful comments from Stephen Biggs, Edward Clay, Ken Ingersent, Stan Metcalfe, Tony Rayner and Bruce Traill are acknowledged. An earlier version of this paper was given at the University of Nottingham Economics Seminar. The participants are also thanked for their help.

pp.264-5 in the second edition of the Theory of Wages, 1963). This little disagreement between Cambridge and LSE later expanded in terms of content and geography, to become the Cambridge controversy.

Hicks himself, in his Nobel lecture of 1973, referred back to this early work, admitting that,

"It seemed to me that rises in wages (rises, that is, in the share of the Product going to Labour per unit of Labour) would encourage the adoption of inventions which economised in Labour and so were biased against Labour; but whether such 'induced inventions' were to be regarded as shifts in the Production Function, or as substitutions within an unchanged Production Function, ws left rather obscure" (reprinted in Hicks, 1977, p2).

As a result, the induced innovation hypothesis was not readily accepted by economists. In his survey of process innovations, Blaug (1963) refers to "the troublesome notion of innovations induced by changes in factor prices - this would seem to involve factor substitution, not technical change." Indeed, Salter's (1960) refutation of inducement was favourably received by economists. He argued that, "at competitive equilibrium, each factor is being paid its marginal value product; therefore all factors are equally expensive to firms" (1960, p.16). Factor substitution ensures that this efficiency condition will be re-established so that no factor is ever "relatively expensive". Thus, "the entrepreneur is interested in reducing costs in total, not particular costs such as labour costs or capital costs. When labour costs rise, any advance that reduces total cost is welcome, and whether this is achieved by saving labour or capital is irrelevant" (1960, pp.43-44).

Clearly, Salter does not reject factor substitution and it is the problem of differentiating this from induced innovation that underlies his objection to the concept. Intending to keep logically separate the technological possibilities and the economic forces that determine the techniques actually in use (1966, p.15), "Salter defined the production function to embrace all possible designs conceivable by existing scientific knowledge and called the choice among these designs 'factor substitution' instead of 'technical change' (Hayami and Ruttan, 1985, p.86). As Rosenberg (1976, p.65) points out, factor substitution then swallows up much of technical change since the production function is no longer a set of blueprints on the shelf, but is also the "much wider range of techniques which could be designed with the current stock of knowledge" (Salter, 1960).

Indeed, Salter's definition of the isoquant is practically identical to Ahmad's (1966) definition of the innovation possibility curve, which is the device he used to rehabilitate the induced innovation hypothesis. The innovation possibility curve remains the basis of the Hayami and Ruttan (1985) presentation of the hypothesis. However the crucial differences are in the level of aggregation and the time frame. Whereas Ahmad considered the business firm, in what has since been called the "secular period", Hayami and Ruttan apply the same concepts to aggregate agricultural output in a long-run historical context.

The model has since been reformulated by Thirtle (1985b) and extended by Binswanger (1978b, 1978c) to include the research process that generates the new technology. Binswanger adopts Evenson and Kislev's (1976) stochastic model of applied research and follows the non-agricultural work of Kamien and Schwartz (1969). The "isotech" analysis of Nordhaus (1973), which has been extended by McCain (1977) and Wyatt (576) is similar to the Hayami and Ruttan approach, but has not been taken on board by agricultural economists. These developments are more fully outlined by Thirtle and Ruttan (1987).

These developments are of a fairly straightforward theoretical nature. At a more practical level, the Hayami and Ruttan model, which has now been around for twenty years, has evolved into a basis for approaching agricultural development, if not actually a theory of agricultural development. This "development model" which should be distinguished from the simple "induced innovation hypothesis", includes the particularly radical step of endogenising (induced) institutional change.

This development model is briefly considered next.

(3) THE INDUCED INNOVATION HYPOTHESIS IN ECONOMIC DEVELOPMENT

Hayami and Ruttan (1985, p.3) do not claim that induced inovation is a "model of development" but only that the "model represents a significant advance in the foundations upon which a more complete theory of economic development can be built". Closer to the point, they argue (p.4) that, "our basic hypothesis is that a common basis for success in achieving rapid growth in agricultural productivity is the capacity to generate "technical change that facilitates the substitution of plentiful (hence cheap) factors of production for scarce (hence expensive) factor inputs. But the model also "attempts to make more explicit the process by which technical and institutional changes are induced through the responses of farmers, agribusiness entrepreneurs, scientists, and public administrators to chanages in the supply and demand of factors and products" (p.4). Further, factor price-guided technological change is a necessary condition for productivity growh, but not sufficient, since it must be complemeted by investments in education, in land infrastructure and by appropriate institutional change (p.5).[2]

By now it is obvious that the model of induced innovation is very broad indeed and that the basic hypothesis is a part of the model rather than a solitary testable proposition. However, it is made clear

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[2]. Making institutional change endogenous broadens the model enormously, but raises considerable methodological difficulties. Induced institutional change is mentioned in places below, but is need not treated as a crucial aspect of the development model, although this aspect should be more fully covered. For critical appraisals see Field (1981) and Grabowski (1988).

(p.85) that Hicks' original proposition (now a very small part of the model) is still considered crucial and it is this proposition that is actually tested by Hayami and Ruttan (1985, Ch.7). Logarithms of factor ratios are regressed on logarithms of factor price ratios. The signs of the coefficients of the price ratios may corroborate or contradict the Hicks proposition of induced innovation.

It seems fair to suggest that the hypothesis being tested[3] is that, ceteris paribus, changes in factor ratios (are the result of technical changes that) have been "induced to a significant extent by the long-term trends in relative factor prices" (p.181). That the causality runs from prices to factor ratios is not tested and nor is the assumption that long-run factor substitution depends upon technical change. These relationships follow from the model and are imposed a priori. To "a significant extent" means that other, omitted variables should not dominate factor prices in the determination of factor ratios. Even so, a ceteris paribus clause is implicit in the hypothesis, as in most economic models.

(4) CRITIQUES OF INDUCED INNOVATION

Criticisms of the hypothesis and the development model are not separated because many of the problems raised apply to both. Instead, the points are divided into methodological, theoretical and empirical issues, beginning with the most contentious area of methodology. Though the writer has sympathies with recent work such as Caldwell (1982) and even the rhetorical and non-scientific approach to the subject stressed by McCloskey (1986), most of us non-specialists best understand the rather naive logical positivism of, say Blaug (1980), which has the advantage of furnishing some very straightforward points.

1) Methodological Issues

Irrefutability As it stands, the suggested testable hypothesis stated in the last section, is irrefutable, but it is in good company since, "exactly the most admired scientific theories simply fail to forbid any observable state of affairs" (Lakatos, 1970, p.100). Irrefutability results from an implicit protective belt of ceteris paribus assumptions that can be invoked when empirical reults contradict the theory.

In this situation, Ruttan et.al. (1978) postulate "an innate labour saving bias" in the technological possibilities.[4]

Alternative hypotheses Partly because there is no state of affairs that the hypothesis forbids, the broader development model is not just irrefutable but has no clear limits, especially when institutional

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3. Empirical investigation of other elements of the model will be considered later.

4. "Scientific honesty then consists of specifying, in advance, an experiment such that if the result contradicts the theory, the theory has to be given up." (Lakatos, p.96).

change is included. Thus, it is hard to see how a potential alternative hypothesis can avoid being swallowed to become a part of a broader and perhaps less neoclassical induced innovation model. For instance, the hypothesis that the relative power of interest groups may determine changes in factor ratios rather than factor prices, appears to be an alternative hypothesis. Yet, the work of de Janvry and Dethier (1985) and de Janvry, Sadoulet and Fafchamps (1987, 1988), which stressed this and other important points, could be called the political economy of induced innovation. Hence, de Janvry, Sadoulet and Fafchamps (1988, abstract) simply claim that when transactions costs are included, "structural and political factors are additionally important determinants of the bias of technology".

Corroboration As Ruttan et.al. (1978, p.65) have noted, results that are consistent with the induced innovation hypothesis may also be consistent with several other plausible theories. For example, Thirtle (1985a) found that for U.S. agriculture from 1939-78, the more labour-intensive a crop was at the beginning of the period, the greater the labour saving bias of technical change. This result appears to corroborate Binswanger's (1978a) statement of the inducement hypothesis, but it could equally well be taken to corroborate Wolff's Law, which basically argues "that the scope for improvement in any technology is limited and that the cost of incremental improvement increases as the technology approaches its long run peformance level". (Freeman 1982, p.216). In the case of the empirical evidence above, Wolff's Law would predict that the cost of mechanisation would be lowest for the least mechanised crop.

Independent data There is a well accepted rule in modelling relationships that the data from which the model is derived cannot be used to test its performance. Extraneous data are required for this purpose. Since it is fairly clear that the induced innovation model was formulated on the basis of historical data for Japan and the U.S.A., the original tests are of dubious validity. However, it is now clear that the agricultural relationships tested for these countries do apply to many other countries and sectors.

Genetic versus teleological development These terms were used in the great development debate of the 1920's in the Soviet Union. Genetic development "lays stress on the existing situation: market forces, relative scarcities of factors, rates of return, profitability". Teleological development "reflects a desire to change the proportions and size of the economy, to maximise growth, to emphasise strategy of development rather than adaptation to circumstances." In fact, "all planning, in the sense of deliberate decision-making affecting the use of resources, must represent some sort of compromise between (these) two principles" (Nove 1969, p.132).

The induced innovation hypothesis stresses that the factor saving biases of technical change must be guided by factor scarcities. Some critics have argued that this puts too much importance on the initial constraints, or even that it means relying on the market do to everything. Alternatively, development planning should aim at changing the status quo and the induced innovation hypothesis is too passive, too genetic.

This is an odd argument to apply in the sense that technical change does alter the resource constraints the economy faces. Rather than going along with comparative advantage, it tends towards destroying it. Put another way, it is anti-trade biased. Induced innovation is teleological in its results, but genetic in the sense that it does take the initial conditions seriously. This would seem to be a considerable strength, rather than a weakness.

Similarities and differences A similar point of criticism is that, in some sense, the induced innovation model is derived from the agricultural histories of the now-developed countries and applies these lessons of history to the present LDCs. Long ago, Gerschenkron (1962) argued that though there are observable regularities in the development process, the very fact of backwardness will lead to systematic deviations from the historical case. Some critics would argue that induced innovation does not provide any guidance on these deviations and may even be misleading because it ignores such differences.

A logical fallacy Elster (1983) attribute the appeal of the Hicksian proposition to "an easily committed logical fallacy". If wages are rising relative to capital costs, then for entrepreneurs collectively, labour-saving innovation seems to be appropriate. But labour-saving innovation will allow factor substitution that will reduce wages and since entrepreneurs act individually, rather than collectively, "the proposed explanation fails.

2) Theoretical Problems

The induced innovation hypothesis can be criticised at several levels. Here, the emphasis will be on shortcomings within the neoclassical framework. This does not imply any rejection of alternative paradigms. Indeed, it is difficult not to agree with Nelson and Winter (1982) that the comparative static basis of neoclassical economics, derived from classical mechanics,[5] is a poor foundation for the study of technological change. But evolutionary models, discussed at greater length in Thirtle and Ruttan, 1987, pp.73-79) are still in their infancy.

Nor need the Cambridge critique be entirely ignored. Indeed, the author's own work in agricultural economics resulted from the hunch that investigating the induced innovation hypothesis in a sector with two non-reproducible factors of production (labour and land) made better sense than in a sector which only labour can be regarded as an original factor of production.

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[5]. Economists are not alone in questioning these issues, and indeed the sciences have long since moved on. "The models considered by classical physics seem to us to occur only in limiting situations such as we can create artificially by putting matter into a box and then waiting until it reaches equilibrium". (Prigogine and Stengers, 1984, p.9).

Pareto optimality Beckford's (1972) original criticisms of the development model point out that if price signals are to guide the path of technical change efficiently, the conditions required for a Pareto optimal allocation of resources would have to hold. That this is most unlikely in a developing economy is well understood.

Aggregation Inappropriate aggregation is not the sole preserve of neoclassical economics, but neoclassicists do seem to sin unduly in this regard. In studying factor ratios and factor price ratios at the national aggregate level, much crucial information is lost. If the factor ratios and/or factor price ratios facing landlords and tenants or resource rich and resource poor farmers are entirely different, than an aggregate model may predict very poorly. Indeed, the political power of different rural interest groups and the responses of the national and international researcher interest groups become central to the outcome. Hence, the more pronounced are inequalities between classes or between regions, the less adequate will be an aggregate induced innovation model. In this sense, induced innovation fails to handle extreme inequality well. However, more complex models of inducement can and do incorporate such factors.

Factor substitution and technical change This paper began with Hicks' admission that the distinction between these concepts was left unclear. Indeed, the distinction was rejected by Brozen (1953) as being "non-operational". Unfortunately this message has not yet reached many neoclassical economists, who, as a result, find the induced innovation model unpalatable. The difficulty is fully discussed in Thirtle and Ruttan (1987, pp.24-25).

Choice of Exogenous Variables The inducement hypothesis is not helped by having a choice of three causal variables. In Hayami and Ruttan (1985), changes in factor ratios are the result of changes in factor price ratios. In the Kennedy-Weizsacker model, the driving force is the ratio of factor shares. In Binswanger (1978b) it is the present value of expected factor costs that motivates research resource allocation. All three appear sensible in the context in which they appear, but the last is particularly worrying. Factor cost should be determined by factor price multiplied by factor quantity. But, following Hayami and Ruttan's reasoning, factor scarcities mean high factor prices, and vice versa. So price times quantity may wash out all inducement information. Fortunately, there is a reasonable explanation for this apparent disagreement.

What is held constant Definitions of the factor saving bias of technical change rest on studying the change in one ratio of economic entities while another is held constant (Thirtle and Ruttan, 1987, pp.12-17). Hence, Hayami and Ruttan consider national aggregates and hence treat factor ratios as relatively fixed, while Binswanger considers the production of particular crops at farm level. Hence, factor ratios for any crop are treated as variables.

Omitted variables The methodological critique of the last section began with a discussion of the application of a ceteris paribus clause to omitted variables. Induced innovation typically considers that factor prices reflect the demand side of the technical change equation. The supply side is less well understood, since the supply of labour-saving mechanical technical changes will be more or less cheap than the supply of land saving biological innovations,[6] according to the scientific possibilities, which tend to be unknown.

Hence, if the demand-driven hypothesis is contradicted by the empirical evidence, cost differences on the supply side are invoked, as was explained above. In terms of the model, such cost differences mean that the innovation possibility curve (IPC) shifts non-neutrality. The results required by the inducement hypothesis follow for sure only if the IPC shifts neutrally, which as Nordhaus (1973) has pointed out, is as bad as imposing Hicks neutral technical change in the first place. Hacche (1979) also regards this problem as the most serious objection to the induced innovation model.

Specification errors The problem of omitted variables, discussed above, is a part of the broader issue of errors in the specification of the model. Thirtle (1985a, 1985b) has shown that Ruttan et.al. (1978) did not need to suggest "an innate labour saving bias" to technical change. Even within the inducement hypothesis, confining the tests to the relationship between factor ratios, technical change and factor price ratios, a more careful formulation of the model produces empirical results that corroborate the hypothesis.

Exogeneity This is a further aspect of model specification, which has not been discussed in this context. Induced innovation models treat the price of land as an exogenous variable. Indeed it is the coefficient of the price of land relative to labour that has positive signs (the hypothesis predicts negatives) in five out of nine cases in Ruttan et.al. (1978, p.63). Though this result can be reversed by re-specifying the model, this may be only a partial correction, since there is considerable evidence that the price of land is endogenous to the system (Traill, 1980, Phipps, 1984, Alston, 1986). For example, if policies such as price supports raise the value of agricultural output, competition amongst producers should lead to the capitalisation of expected extra profits in land values. Put another way, if output prices rise, the area of producer's surplus should increase and producers surplus represents rents accruing to those factor inputs that least elastic in supply (i.e. land).

When the increased profitability is caused by land-saving technical change, the position is less clear, since there should be substitution of land substitutes for land, causing its share to diminish. However,

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[6]. This difference is aggravated by the fact that the majority of mechanical innovations emanate from the private sector, while biological innovations were, until recently, largely the province of the public sector.

where technical change has been accompanied by price supports, so that the gains from technical change are not passed on to consumers in the form of lower prices, it seems clear that landlords gain much of the benefit. The exogenous-price, substitution along the isoquant model seems to be inappropriate. Indeed, it would only make sense if land prices are causally prior to changes in factor ratios. It seems unlikely, for instance, that land prices are Granger-prior (Thurman and Fisher, 1988) to land/fertilizer or land/labour ratios. Indeed, Phipps (1984) found that farm returns were Granger-prior to farmland prices.

Errors in variables "There is no natural demarcation between observational and theoretical propositions" (Lakatos, 1972, p.99). So, theories cannot be confronted with hard, proven facts, since these too rest on theories. This is especially true of the data required for empirical investigations of induced innovation. Indeed, empirical results that appear to be contrary to the theory have been reversed when more care has been taken with data on the U.S. land prices seres (Hayami and Ruttan, 1985, Ch.7) and the Japanese labour data.

Technical change in agriculture Kislev and Peterson (1981) have argued that mechanical technical change is technical change in the farm machinery industry, rather than in agriculture and that changes in factor ratios in agriculture can be explained entirely by factor substitution (Kislev and Peterson, 1982). There is some truth to the first claim, although product innovation in the capital goods industry is frequently process innovation in the consumer goods industry (Blaug, 1963), and it is easier to measure process innovation. One possibility is to concentrate on measuring technical change in the vertically integrated agricultural sector (Rayner, Whittaker and Ingersent 1986).

3) Empirical Limitations

The vast majority of empirical work, which is reviewed in the next section, invesigates only the basic hypothesis of the link between factor ratios and factor prices. An important exception in Guttman's (1978) empirical analysis of interest groups, which explains the allocation of agricultural research funds in the U.S.A. Alderman (1984) includes infrastructure and political elements in his analyses. Lastly, de Janvry, Sadoulet and Fafchamps (1987) include variables such as asset distribution, farm size and the size of the research budget, while the same authors (1988) include structural and political factors in their empirical work.

Further empirical analysis of this type is clearly required to establish all the aspects of the development model that go far beyond the basic factor price/factor ratios hypothesis. The empirical tests of this relationship are numerous and will be considered next.

(4) EMPIRICAL INVESTIGATIONS OF THE INDUCEMENT HYPOTHESIS

Empirical analyses of the relationships between factor-specific technical change and factor prices are discussed in some detail in Thirtle and Ruttan (1987, pp.49-73). Here, the evidence is presented in the form of tables, which allows rapid assimilation. Table Ia, Ib and Ic cover agricultural studies of the USA, Japan and other countries, respectively. Table IIa covers industrial studies and IIb considers work in economic history. In all there are 96 studies listed and the overwhelming majority corroborate the induced innovation hypothesis. However, the standards enforced are not terribly exacting. Usually, all that is required is that the factor saving biases should have the right sign, though some studies do look at relative magnitudes. There are a fair number of individual factor biases (marked *) that are contrary to the predictions of the hypothesis, though these are often explained in the text.

The agricultural studies mostly discuss the induced innovation hypothesis, but most do not go beyond fitting production functions. A few papers, such as Antle (1986), are more inventive and some go well beyond the simple hypothesis (de Janvry, et.al., 1988).

The industrial studies begin with simple, two factor, production function estimates of the factor-saving biases of technical change. The fashion changes to KLEM models, flexible functional forms and duality, but again there is little evidence of originality of thought in most papers. Morishima and Saito's (1968) paper which excludes structural change from the measures of biases and Davidson's (1976) completely different approach, are fairly rare exceptions.

Generally, there is no lack of parameter estimation, but there is scope for far more careful interpretation and for comparisons of different studies in order to identify the major differences and explain them.

Table Ia : Summary of Empirical Studies of Induced Innovation in Agriculture - USA (see notes at foot of Table Ic for meaning of symbols)

Study and Reference	Crop, Area and Time Period	Methodology	Factor Biases	Consistency of Results with Induced Innovation
1) Hayami & Ruttan (1971)	National Aggregate, 1880-1960	Regression of factor ratios on factor price ratios	Not estimated	Consistent with induced innovation
2) Hayami & Ruttan (1985)	National Aggregate, 1880-1980	" " "	" "	Consistent with induced innovation but not all coefficients are significantly different from zero
3) Binswanger (1974) (1978)	National Aggregate, 1912-1968	Translog cost function	LAND - (slight) LABOUR - (after 1948) MACHINERY + FERTILIZER + OTHER none	Consistent
4) Kislev & Peterson (1981)	National Aggregate, 1930-1970	Implicit two stage CES production function	No technical change	Contrary in the sense that factor substitution explains all changes without reference to technical change
5) Weaver (1983)	Wheat, North and South Dakota 1950-1970	Translog profit function	LABOUR - CAPITAL - FERTILIZER + PETROLEUM PRODUCTS +	Consistent
6) Thirtle (1985a) (1985b)	Wheat, Soybeans, Corn and Cotton, 10 US Farm Produc-Regions, 1939-1978	CES/Cobb-Douglas	LABOUR-SAVING BIAS	Consistent
7) Thirtle (1985c)	Corn, 10 US Farm Produc-Regions, 1939-1978	Two stage CES production function	LAND + slight LABOUR - strong MACHINERY + strong FERTILIZER + strong	Consistent
8) Thirtle (1985d)	Wheat, Soybeans, Corn, Cotton, 10 US Farm Production Regions, 1939-1978	Calculated from the data using 2 stage CES estimates of substitution elasticities	LABOUR SAVING BIAS	Consistent
9) Hayami & Ruttan (1985)	National Aggregate, 1880-1980	Two stage CES production function	LAND - LABOUR - MACHINERY + FERTILIZER +	Consistent
10) Chambers & Lee (1986)	National Aggregate 1947-1980	Translog indirect production function	LAND - LABOUR - CAPITAL + MATERIALS +	Consistent

Table 1a continued.

Study and Reference	Crop, Area & Time Period	Methodology	Factor Biases	Consistency of Results with Induced Innovation
11) Antle (1984)	National Aggregate, 1910-1978	Translog profit function	1910-46: LABOUR +, CAPITAL +, CHEMICALS 0, LAND - 1947-78: LABOUR -, CAPITAL +, CHEMICALS +, LAND 0	Consistent, particularly in the long run
12) Antle (1986)	National Aggregate, 1910-1978	Basis explained econometrically by prices ratios, with lags	Shows that the induced innovation hypothesis offers an explanation of some of the biases, but is not sufficient on its own	Mainly consistent
13) Capalbo and Denny (1986)	Aggregate data, 1962-78	Translog Function	Fails to reject Hicks neutrality	No outcome
14) Chambers and Lee (1986)	National aggregate 1947-1980	Translog Indirect Production Function	LAND - LABOUR - CAPITAL + MATERIAL +	Consistent
15) Kawagoe, Otsuka and Hayami (1986)	National Aggregate 1880-1925 1930-1980	2 stage CES production function	LAND + LABOUR - MACHINERY - FERTILIZER +	Consistent
16) Shoemaker (1988)	National Aggregate, 1948-1979	Translog cost function	LAND - LABOUR - CAPITAL + ENERGY + MATERIALS +	Consistent
17) Ball (1987)	National Aggregate, 1948-1979	Translog restricted profit function	Biases are not significant	-
18) Offutt and Shoemaker (1987)	National Aggregate, 1948-1984	Translog cost function	LAND - LABOUR - CAPITAL + MATERIALS +	Consistent

Table Ib : Summary of Empirical Studies of Induced Innovation in Agriculture - Japan

Study and Reference	Crop, Area and Time Period	Methodology	Factor Biases	Consistency of Results with Induced Innovation
1) Sawada (1970)	National Aggregates 1883-1963	2 factor CES production function	LAND - before 1931 LABOUR + LAND + after 1946 LABOUR -	Consistent
2) Hayami & Ruttan (1971)	National Aggregates 1880-1960	Regression of factor ratios on factor price ratios	Not estimated	Consistent with induced innovation in two cases out of three
3) Hayami & Ruttan (1985)	National Aggregates 1880-1960	Regression of factor ratios on factor price ratios	Not estimated	Consistent
4) Binswanger (1973)	National Aggregates 1900-1970	Translog cost function	LAND - LABOUR + before 1928 - after *MACHINERY - FERTILIZER +	Mainly consistent
5) Yeung and Roe (1978)	National Aggregates 1880-1940	Modified 2 factor CES	* LAND + * LABOUR -	Contrary to induced innovation
6) Kako (1978)	Rice in Kinki District	Translog cost function	LAND - strong LABOUR - strong MACHINERY - slight FERTILIZER - slight OTHER - very slight	Consistent
7). Nghiep (1979)	Rice, national, 1905-39	Translog cost function	LAND - * LABOUR - MACHINERY + FERTILIZER +	Mainly consistent
8) Lee (1983)	Rice, 4 prefectures	Translog production function	LAND + 2 out of LABOUR - 3 sub-periods MACHINERY - strong * FERTILIZER - *& PESTICIDE -	Mainly consistent
9) Alderman (1984)	National Aggregates 1902-1940	Translog cost function	LAND - * LABOUR - CAPITAL + CURRENT INPUTS + (Mainly Fertilizer)	Mainly consistent
10) Hayami & Ruttan (1985)	National Aggregates 1880-1980	Two stage CES production function	LAND not clear LABOUR - MACHINERY + FERTILIZER +	Consistent
11) Grabowski and Sivan (1983)	National Aggregates, 1874-1971	Weak disposability of inputs production function	* LAND + * LABOUR -	Contrary to the hypothesis
12) Kawagoe, Otsuka and Hayami (1986)	National Aggregates, 1880-1940 1955-1980	Two Stage CES production function	LAND - LABOUR - MACHINERY + FERTILIZER	Consistent

Table Ic : Summary of Empirical Studies of Induced Innovation in Agriculture - Other Countries

Study and Reference	Country	Crop, Area, and Time Period	Methodology	Factor Biases	Consistency of Results with Induced Innovation
1) McKay, Lawrence & Vlastuin (1982)	Australia	Sheep and wool, crops, beef cattle, and other farm output in the Australian wheat/sheep zone, 1952-77	Translog variable profit function	LAND - slight LABOUR - strong CAPITAL + strong *MATERIALS - slight	Mainly consistent
2) Lopez (1980)	Canada	National Aggregates, 1946-1977	Generalised Leontief cost function	Increasing returns to scale and no technical change	Contrary
3) Capalbo and Denny (1986)	Canada	National Aggregates, 1962-78	Translog production function	Fails to reject Hicks neutrality	No outcome
4) Adamowicz (1986)	Canada	National Aggregates, 1926-81	Translog cost function	LAND - LABOUR - CAPITAL + MATERIALS + FEED + FUEL +	Consistent
5) Ahmad & Kubursi (1977)	Egypt and Syria	(For V. Ruttan to complete)			
6) Ruttan et.al. (1978)	Denmark	National Aggregates, 1910-1965	Regression of factor ratios on factor price ratios	Not estimated	Mainly consistent, but the behaviour of the land/labour ratio in Denmark, France and the U.K. is not explained by the relative factor prices
	France	" 1870-1965	"	"	
	Germany	" 1880-1968	"	"	
	United Kingdom	" 1870-1965	"	"	
7) Ruttan et.al. (1978)	Germany	Livestock Production			
		" 1880-1968	"	"	
		" 1880-1925	"	"	
		" 1870-1965	"	"	
8) Binswanger (1977)	USA	National Aggregates, 1880-1970	International comparisons of residual measures of land & labour-saving technical changes	Labour-saving	General support
	Japan	" "		mainly neutral	
	Great Britain	" "		labour-saving	
	France	" "		slightly labour-saving	
	Germany	" "		"	
	Denmark	" "		"	
9) Fare, Grabowski and Yoon (1984)	Korea(South)	National Aggregates 1918-1971	Weak disposability of inputs production function	LAND - FERTILIZER +	Consistent

Table Ic continued

Study and Reference	Country	Crop, Area, and Time Period	Methodology	Factor Biases	Consistency of Results with Induced Innovation
10) Park (1986)	Korea (South)	Rice, 1963-1984	Regression of factor ratios on factor price ratios	Not estimated	Consistent
11) Grabowski and Sanchez (1987)	Mexico	Aggregate, 1950-1979	Weak disposability of inputs production function	LAND - *LABOUR - MACHINERY + FERTILIZER +	Mixed result
12) Barlow and Jayasuriya(1984)	Malaysia	Rubber, 1922-1978	Cost calculations	LAND - LABOUR - CAPITAL +	Consistent, but a bias in favour of plantations relative to small-holders
13) Grabowski, Sivan and Tracy (1986)	Taiwan	Aggregate, 1911-45 1945-72	Variable elasticity of substitution	-1945 1945- LAND - + LABOUR + -	Consistent
14) Johnson (1972)	New Zealand	National Aggregates, 1945-1967	CES production function	LABOUR - CAPITAL +	Consistent
15) Godden (1985)	United Kingdom	National Aggregates, 1950-1980	General linear variable profit function	LAND - LABOUR - No result PLANT + *MATERIALS -	Unclear, generally poor results
16) de Janvry, Sadoulet and Fafchamps (1987, 1988)	Cross section	-	Regression of factor ratios on factor prices and other variables	LAND - LABOUR - No result PLANT + *MATERIALS -	Surprisingly consistent, but structural variables matter too

For attempts to examine the social and political aspects of induced innovation see de Janvry (1973), (1977), Feeny (1983), Sanders and Ruttan (1978) and de Janvry and Dethier (1985).

NOTES For factor biases (-) indicates factor-saving technical change and (+) indicates that technical change was factor-using. The symbol * against a factor bias indicates that it is either contrary to the direction indicated by the inducement hypothesis or explanation by the author is required to reconcile it with the theory.

Table II(a) : Summary of Empirical Studies of Induced Innovation in Industry

Study and Reference	Country, Industry and Time Period	Methodology	Factor Biases	Consistency of Results with Induced Innovation
1) Brown and Popkin (1962)	US non-farm domestic sector, 1890-1958	Cobb-Douglas production function parameter estimates are used in comparisons of "technological epochs"	1890-1918} LABOUR-SAVING 1919-1937} 1938-1958 } LABOUR-SAVING	The labour-using result is clearly contrary to the induced innovation hypothesis.
2) Resek (1963)	US non-farm domestic sector, 1919-1959	Regression of factor ratio on factor prices	LABOUR-SAVING	Consistent
3) David & Van de Klundert (1965)	US private domestic economy, 1899-1960	CES production function	LABOUR-SAVING	Consistent
4) Ferguson (1969)	Several US industries, 1949-1961	CES production function	GENERALLY LABOUR-SAVING	Mainly Consistent
5) Sato (1970)	US private non-farm sector, 1909-1960	CES and CEDD (constant elasticity of derived demand) production functions	LABOUR-SAVING	Consistent
6) Takayama (1974)	US non-agricultural private sector 1909-1960	Linear regression of several "simple formulas"	LABOUR-SAVING	Consistent
7) Panik (1976)	US private domestic sector 1929-1966	CES production function	LABOUR-SAVING	Consistent
8) Zind (1979)	US private non-farm sector 1909-1960	Linear regression estimation of coefficients of underlying relationships, similar to Takayama [444]	LABOUR-SAVING	Consistent
9) Gupta and Taher (1984)	US textile industry 1949-1974	Translog cost function	LABOUR-SAVING	Consistent
10) Bergstrom and Melander (1979)	Swedish Industry in aggregate and eight industries 1950-1973	Input demand functions from a CES	LABOUR-SAVING	Consistent
11) Forsund and Jansen (1984)	Norwegian Aluminium industry 1966-1978	Comparison of cost-minimising factor ratios, as in Salter [390]	LABOUR-SAVING	Consistent
12) Morishima and Saito (1968)†	US domestic economy 1902-1955	Differentiates between autonomous and induced innovation and includes structural change. A proper test of induced innovation based on the CES	Induced innovation is: PRACTICALLY NEUTRAL 1902-1929 CAPITAL-SAVING 1929-1938 LABOUR-SAVING 1938-1955	Consistent

Table II(a) continued.

Study and Reference	Country, Industry and Time Period	Methodology	Factor Biases	Consistency of Results with Induced Innovation
13) Fellner (1971)[†]	US two digit manufacturing industries 1948-1957	Regression of increase in factor ratio on the rate of change of the factor price ratio	Suggests labour-saving innovations	Consistent
14) Berndt and Wood (1975)	US manufacturing, 1947-1971	Translog cost function	CAPITAL, LABOUR, ENERGY, MATERIALS } Could not reject Hicks' neutrality	Inconsistent
15) Belinfante (1978)	460 observations on 80 US steam-electric generating plants of 1947-59 vintage	Total factor productivity study based on Divisia indices	Little evidence of biases	Inconsistent
16) Wills(1979) [†]	US primary metals industry, 1948-1974	Translog cost function	LABOUR - ENERGY - MATERIALS - CAPITAL +	Consistent. The rates of factor augmentation are shown in descending order; the ordering of the rates of price increase is the same.
17) Berndt and Khaled (1979)	US manufacturing, 1947-1971	Generalised Box-Cox cost function	CAPITAL + LABOUR - *ENERGY + MATERIALS -	Mainly consistent
18) Stevenson (1980)[†]	US electricity generating firms for 1964 and 1974	Translog cost function	*CAPITAL - LABOUR - FUEL +	The author finds no evidence to support the hypothesis but see (23).
19) Jorgenson and Fraumeni (1981)	Thirty-five US industries, 1958-1974	Translog cost function	CAPITAL + (25) industries *LABOUR + (31) industries ENERGY + (29) industries MATERIALS -(33) industries	Contrary
20) Moroney and Trapani (1981)	Six US natural resource intensive industries 1955-1974	Translog cost function	CAPITAL + (3) industries) LABOUR - (6) industries NATURAL RESOURCES + (5) industries SCRAP METAL + (2) industries (Scrap was used in only 2 industries)	The dominant pattern of labour-saving and natural resource-using technical change is consistent with relative input price movements.
21) Woodward (1983)	US non-farm private sector, 1948-1978 US manufacturing sector, 1958-1977	Translog cost function	CAPITAL - strong LABOUR - strong ENERGY - weak MATERIALS - weak	Mainly consistent. Energy price have a slight effect.

Table II(a) continued.

Study and Reference	Country, Industry and Time Period	Methodology	Factor Biases	Consistency of Results with Induced Innovation
22) Greene (1983)	US electric power companies 1955-1975	Translog cost function	CAPITAL - LABOUR - (since 1965) FUEL +	Unclear. The prices of capital and labour were rising relative to that of fuel almost to the end of the period.
23) Gollup and Roberts (1983)	US electric power industry 1973-1979	Translog cost function	CAPITAL - LABOUR - FUEL +	Unclear.
24) Lau and Tamura (1972)	20 Japanese petrochemical plants of vintage 1958-1969	Input demand functions from a modified Leontief production function	CAPITAL, LABOUR, ENERGY, MATERIALS } Hypothesis of zero technical change could not be rejected	Contrary
25) Duncan and Binswanger (1974)†	14 Australian manufacturing industries 1948-1967	Translog cost function	7 factors	Mild support, but results unclear
26) Duncan and Binwanger (1976)†	Energy use in Australian manufacturing industries 1948-1967	Translog cost function	COAL - FUEL OIL unclear ELFCTRICITY + COAL GAS unclear	Perhaps mild support
27) Levy (1981)	Iraq, industrial sector, 1961-1967	Translog profit function	LABOUR-SAVING	Not really contrary. Wages were rising and Iraq is not short of capital
28) Lynk (1982)	15 Indian industries, 1952-1971	Generalised Leontief cost function	CAPITAL + PLANT + LABOUR -	Contrary
29) Norsworthy and Malmquist (1983)	Japanese manufacturing 1965-1978	Translog cost function	CAPITAL + LABOUR - ENERGY - MATERIALS -	Unclear
30) Rao and Preston (1984)	Canadian industries 1957-1979	Translog cost function	Predominantly CAPITAL - *LABOUR neutral ENERGY + MATERIALS +	Contrary
31) Daly and Someshwar Rao (1985)	Ontario Hydro, 1967-1980	Translog cost function	CAPITAL - LABOUR - ENERGY + MATERIALS +	Mainly consistent
32) Davidson (1976)	UK, Japan, Europe and USA - individual innovations of the period 1945-74	International comparisons of the ordering of relative factor costs and the factor-saving biases of 255 process innovations and 315 product innovations	Counts of Capital-saving Material-saving Labour-saving innovations	Mainly consistent. "Factor endowment significantly influences innovation trends in the industrialised world"

Table II(a) continued.

Study and Reference	Country, Industry and Time Period	Methodology	Factor Biases	Consistency of Results with Induced Innovation
33) May and Denny (1978)	US manufacturing, 1949-70	Translog production function	LABOUR – CAPITAL 0 MATERIALS 0	Not inconsistent
34) Turnovsky, Folie, Ulph (1982	Australian manufacturing 1946-75	Translog cost function	LABOUR – CAPITAL + MATERIALS 0 ENERGY +	Consistent
35) Heng (1985)	20 Singapore manufacturing industries, 1963-81	CD, CES and Translog production functions	Labour augmentation greater than capital augmentation	Consistent, if the claims that there is labour scarcity is accepted
36) Hunt (1986)	UK Industrial sector, 1960-80	Translog cost function	LABOUR – CAPITAL + ENERGY +	Consistent
37) Nelson (1986)	22 Electric utilities, 1961-78	Translog cost function, with vintage capital	LABOUR – CAPITAL + FUEL – (1971-78)	Reasonably consistent
38) Mountain (1986)	Swiss manufacturing 1949-76	Translog production function	LABOUR – CAPITAL + IMPORTS –	Consistent
39) Martinello (1987)	4 British Columbian wood products industries, 1963-79	Translog cost function	LABOUR – CAPITAL + MATERIALS 0 or –	Consistent

Table II(b) : Summary of Empirical Studies of Induced Innovation in Economic History

Study and Reference	Country, Industry and Time Period	Methodology	Factor Biases	Consistency of Results with Induced Innovation
1) Asher (1972)	British and American textiles, 19th century	CES production function	LABOUR-SAVING BIAS in both countries	Contrary to the hypothesis since Britain had the greater labour-saving bias.
2) Uselding (1972)	Springfield Armory 1820-1850	CES production function	LABOUR-SAVING BIAS overall	Weak support
3) Uselding and Juba (1973)	American manufacturing 1839-1899	CES production function	LABOUR-SAVING BIAS overall	Weak support
4) Smith (1978)	Springfield Armory 1820-1850	Translog cost function	LABOUR - Insignificant CAPITAL + MATERIALS -	Unclear. The author avoids making too much of the results
5) Cain and Patterson (1981)	19 US manufacturing industries 1820-1919	Translog cost function	LABOUR - (14) industries CAPITAL + (16) industries NATURAL RESOURCES + (12) industries OTHER - (13) industries	Mainly consistent
6) Phillips(1981)†	British coal industry, second half of 19th century	Translog cost function	LABOUR-SAVING BIAS except during the depression	Consistent
7) Phillips(1982)†	Pig iron, cotton textiles, second half of 19th century	Translog cost function	Unclear	Contrary. Nearly all parameter estimates have the wrong sign.
8) Woolf (1984)	15 U.S. industries, 1909-1929	Translog production function	LABOUR - CAPITAL + FUEL 0 or -	Consistent
9) Peterson and Kislev (1986)	U.S. cotton harvesting 1930-1964	Demand and supply equation	LABOUR - MACHINERY +	Contrary, in the sense that 79% of mechanisation is attributed to rising urban wages and only 21% to the decreased cost of machinery
10) Cain and Peterson (1986)	19 U.S. manufacturing industries, 1850-1919	Generalised Leontief production function	LABOUR - CAPITAL + MATERIALS +	Consistent
11) Cohen (1987)	North American pulping, 1914-1940	Cost calculations	Pulping technique innovations saved on more expensive factors	Consistent

NOTES Studies (1)-(12) are two-factor estimates of non-neutral technical change, rather than tests of induced innovation. Papers that explicitly address themselves to testing the induced innovation hypothesis are marked †.

The symbols (+), (-) and * have the same meaning as in Table I. In most instances "consistent" means only that the direction of the factor bias of technical change is the opposite of relative input price changes. The degree of correlation between the two variables

(5) CONCLUSIONS

This paper surveys empirical work on induced innovation, in the context of trying to evaluate the progress made in developing and corroborating two separate, but connected propositions in economics. The more straightforward of the two is the induced innovation hypothesis, which aims to endogenise the factor saving bias (but not the rate) of technological change. The second is the use of induced innovation as the basis for a theory of development.

To begin with the hypothesis, the model of induced innovation has been considerably developed, but has not yet escaped from the need to assume that the innovation possibility curve shifts Hicks-neutrally. It is a demand-side theory, like the classical diffusion model, but whereas modern diffusion models now have a supply side, this has not yet been added to the induced innovation model.

The empirical work on the hypothesis, surveyed in the last section, is beginning to rival the building of the pyramids in terms on man-years of input. The tables give a clear impression that progress is quite rapid. Errors in the empirical specifications of the model have been corrected, errors in data have been lessened, more general functional forms are being used that allow more parameters to be determined endogeneously and recent papers make serious attempts to include omitted variables, so extending the scope of the model.

However, there must be a suspicion that if economists want to advise agricultural scientists and others, on the allocation of research resources, they may need to put their own house in order. Duplication of research efforts is supposed to be a failing of the private sector. In the public sector, open knowledge of research results is supposed to make duplication unnecessary, but the profusion of papers fitting the latest flexible function form to slightly different data, suggests otherwise. Knowledge may be public, but C.V.s are private and authors seek publications as avidly as private firms seek patents. At first glance the results of the large number of tests may seem to lack cohesion; to be less exact than is required by the standards of science. On further reflection, this author agrees with Gerschenkron (1962) that, "The search is not for a formulation of the development process as ubiquitous and invariant as the course of the planets". In non-laboratory, inexact sciences each situation differs and there are no completely general rules.

In methodological terms, problem shifts in this research programme still appear to be progressive, rather than degerate attempts to protect the theory with ceteris paribus assumptions. But what are the research paths to avoid (negative heuristic) and the paths to pursue (positive heuristic)? Perhaps, to avoid repetition estimates of the factor saving biases and apply more effort to modelling the mechanism by which price-induced biases become embodied in new technologies. Do we have an economic theory of the R &

D behavior of the firm, or of public institutions?

Evaluating induced innovation as the basis for a theory of agricultural development is a more emotive and subjective affair. To put the issue in perspective, consider how a planner responsible for allocating resources in agricultural research would act in order to maximise social welfare. Resources would be concentrated on remedying factor scarcities, in order to maximise the gains from research. The basic propositions of induced innovation must be taken on board. But the planner would not settle for national aggregates, except in a first approximation. Distributional weights would have to be agreed, for different classes, with different incomes and for resource-poor versus resource-rich regions. Without these calculations, which many would argue (Chambers, 1983, Chambers and Ghildyal 1985) should have an appropriate poverty focus, social welfare would not be maximised even if agricultural grow was. It is in this sense that the narrow version of the induced innovation model fails to deal with severe inequalities. However, if the model provides a proper framework for thinking agricultural development, such problems should be accentuated rather than obscured. There is no reason why a theoretical framework should detract attention from a clear practical problem.

REFERENCES

Ahmad, S. (1966). "On the Theory of Induced Innovation", Economic Journal, 76, 344-357.

Alderman, H. (1984). "Attributing Technological Bias to Public Goods", Journal of Development Economics, 14, 375-393.

Alston, J.M. (1986). An Analysis of Growth of U.S. Farmland Prices, 1963-82, American Journal of Agricultural Economics, Vol.68, No.1, pp.1-9.

Antle, J.M. (1986). Aggregation, Expectations and the Explanation of Technological Change, Journal of Econometrics, Vol.33, pp.213-36.

Beckford, G. (1972). "Strategies for Agricultural Development: Comment", Food Research Institute Studies in Agricultural Economics, Trade and Development, 11(2), 149-154.

Binswanger, H. (1978a). "Induced Technical Change: Evolution of Thought", Chapter 2 in Induced Innovation, ed. by H. Binswanger and V. Ruttan. Baltimore: Johns Hopkins University Press.

____________ (1978b). "The Microeconomics of Induced Technical Change", Chapter 4 in Induced Innovation, ed. by H. Binswanger and V. Ruttan. Baltimore: Johns Hopkins University Press.

____________ (1978c). "Issues in Modelling Induced Technical Change", Chapter 5 in Induced Innovation, ed. by H. Binswanger and V. Ruttan.

Blaug, M. (1963). "A Survey of the Theory of Process-Innovation", Economica, 63, 13-32. Reprinted in Chapter 4 of The Economics of Technological Change, ed. by N. Rosenberg. Harmondsworth, England: Penguin, 1971.

________ (1980). The Methodology of Economics: or How Economists Explain, Cambridge University Press.

Brozen, Y. (1953). "Determinants of the Direction of Technical Change", American Economic Review, Papers and Processings, 65, 288-302.

Caldwell, B. (1982). Beyond Positivism: Economic Methodology in the Twentieth Century. Allen and Unwin, London.

Chambers, R. (1983). Rural Development: Putting the Last First, Longman, London.

Chambers, R. and Ghildyal, B.P.(1985). Agricultural Research for Resource-Poor Farmers: the Farmer-First-and-Last Model. Discussion Paper 203, Institute of Development Studies, University of Sussex, April.

Davidson, W.H. (1976). "Patterns of Factor-Saving Innovation in the Industrial World", European Economic Review, 8, 207-217.

de Janvry, A. and Dethier, J.J. (1985). The Political Economy of Rate and Bias of Technological Innovations in Agriculture, Working Paper No.341, rev, Department of Agricultural and Resource Economics, University of California, Berkeley.

de Janvry, A., Sadoulet, E. and Fafchamps, M. (1987). Agrarian Structure, Technological Innovations and the State, Working Paper No.442, Department of Agricultural and Resource Economics, University of California, Berkeley.

________________________ (1988). The Optimum Bias of Technological Innovations in the Context of Transactions Costs and Lobbying, Paper for presentation in the symposium on "Induced Innovation Theory and Agricultural Development in LDC, American Agricultural Economics Association meeting, Knoxville Tn, August 2nd.

Elster, J. (1983). "Neoclassical Theories", Chapter 4, and "Evolutionary Theories", Chapter 6, in Explaining Technical Change. Cambridge: Cambridge University Press.

Evenson, R. and Y. Kislev (1975). Agricultural Research and Productivity, New Haven: Yale University Press.

Field, A.J. (1981). The Problem with Neoclassical Institutional Economics: A Critique with Special Reference to the North-Thomas Model of Pre-1500 Europe, Explorations in Economic History, Vol.18, April, 174-181.

Freeman, C. (1982). The Economics of Industrial Innovation, 2nd edition, Pinter, London.

Gerschenkron, A. (1962). Economic Backwardness in Historical Perspective, Harvard University Press, Cambridge, MA.

Grabowski, R. (1988). The Theory of Induced Institutional Innovation: A Critique, World Development, Vol.16, No.3, 385-394.

Guttman, Joel. (1978). "Interest Groups and the Demand for Agricultural Research", Journal of Political Economy, 86, 467-484.

Hacche, G. (1979). The Theory of Economic Growth: An Introduction. London, Macmillan and Co.

Hayami, Y. and V. Ruttan (1985). Agricultural Development: An International Perspective, Rev.Ed. Baltimore: Johns Hopkins University Press.

Hicks, J. (1932). The Theory of Wages, 1st ed. London: Macmillan and Co.

________ (1977). Economic Perspectives: Further Essays in Money and Growth. Oxford: Clarendon Press.

Kamien, M. and N. Schwartz (1968). "Optimal Induced Technical Change", Econometrica, 36, 1-17.

________ (1969). "Induced Factor Augmenting Technical Progress from a Microeconomic Viewpoint", Econometrica, 37, 668-684.

Kislev, Y. and W. Peterson (1981). "Induced Innovations and Farm Mechanisation", American Journal of Agricultural Economics, 63, 562-565.

________________ (1982). "Prices, Technology and Farm Size", Journal of Political Economy, 90(3), 578-595.

Lakatos, J. (1970). Falsification and the Methodology of Scientific Research Programmes, in I. Lakatos and A. Musgrave (eds.) Criticism and the Growth of Knowledge, Cambridge University Press.

McCain, R.A. (1977). "The Characteristics of Optimum Inventions: An Isotech Approach". American Economic Review, 67(1), 365-369.

McClosky, D.N. (1986). The Rhetoric of Economics, Harvester Press.

Morishima, M. and M. Saito (1968). "An Economic Test of Sir John Hicks' Theory of Biased Induced Inventions", in Value, Capital and Growth: Papers in Honour of Sir John Hicks, ed. by J. Wolfe. Chicago: Aldine Publishing Co.

Nelson, R.R. and Winter, S. (1982). An Evolutionary Theory of Economic Change. Cambridge, Mass. Belknap Press of Harvard University.

Nordhaus, W.D. (1973). "Some Skeptical Thoughts on the Theory of Induced Innovation", Quarterly Journal of Economics, 87, 209-219.

Nove, A. (1969). An Economic History of the USSR, Penguin, Harmondsworth.

Phipps, J.J. (1984). Land Prices and Farm-Based Returns, American Journal of Agricultural Economics, Vol.66, No.4, 422-9.

Prigogine, J. and Stengers, I. (1984). Order Out of Chaos: Man's New Dialogue with Nature, Bantam Books.

Rayner, A.J., Whittaker, J.M. and Ingersent, K. (1986). Productivity Growth in Agriculture Revisited: A Measurement Framework and Some Empirical Results, Journal of Agricultural Economics, Vol.37, No.2, pp.127-150.

Rosenberg, N. (1976). Perspective on Technology, New York: Cambridge University Press.

Ruttan, V.W., H. Binswanger, Y. Hayami, W. Wade, and A. Weber (1978). "Factor Productivity and Growth: A Historical Interpretation", Chapter 3 in Induced Innovation, ed. by H. Binswanger and V.W. Ruttan. Baltimore. Johns Hopkins University Press.

Salter, W.E.G. (1960). Productivity and Technical Change, 1st ed. Cambridge: Cambridge University Press.

__________ (1966). Productivity and Technical Change, 2nd ed. Cambridge: Cambridge University Press.

Thirtle, C. (1985a). "Testing the Induced Innovation Hypothesis: United States Agriculture, 1939-78", Journal of Agricultural Economics, 36(1), 1-14.

__________ (1985b). "The Microeconomic Approach to Induced Innovation: A Reformulation of the Hayami and Ruttan Model", The Manchester School, 263-279.

Thirtle, C. and Ruttan, V. (1987). The Role of Demand and Supply in the Generation and Diffusion of Technical Change, Fundamentals of Pure and Applied Economics, Vol.21, Harwood Academic Publishers, London.

Thurman, W.N. and Fisher, M.E. (1988). Chickens, Eggs and Causality or Which Came First?, American Journal of Agricultural Economics, Vol.70, No.2, May, pp.237-8.

Traill, W.B. (1980). Land Values and Rent: The Gains and Losses from Farm Support Programmes. Bulletin No.175, Department of Agricultural Economics, University of Manchester.

Wyatt, G. (1986). The Economics of Invention: A Study of the Determinants of Inventive Activity. Brighton, England: Harvester Press.

STUDIES REFERRED TO IN TABLES I AND II THAT ARE NOT LISTED IN THIRTLE AND RUTTAN (1987)

Adamowicz, W. (1986). Production Technology in Canadian Agriculture, Canadian Journal of Agricultural Economics, Vol.34, March, pp.87-103.

Antle, J.M. (1984). The Structure of U.S. Agricultural Technology, 1910-78, American Journal of Agricultural Economics, Vol.66, No.4, November, pp.414-421.

_________ (1986). Aggregation, Expectations, and the Explanation of Technological Change, Journal of Econometrics, Vol.33, pp.213-236.

Ball, V.E. (1987). Modelling Supply Response of Multiproduct Farms, Working Paper, USDA, Washington.

Cain, L.P. and Paterson, D.G. (1986). Biased Technical Change, Scale and Factor Substitution in American Industry 1850-1919, Journal of Economic History, Vol. XLVI, No.1, March, pp.153-164.

Capalbo, S.M. and Denny, M.G. (1986). Testing Long Run Productivity Models for the Canadian and U.S. Agricultural Sectors, American Journal of Agricultural Economics, Vol.68, No.3, August, pp.615-625.

Chambers, R.G. and Lee, H. (1986). Constrained Output Maximisation and U.S. Agriculture, Applied Economics, Vol.18, pp.347-357.

Cohen, A.J. (1987). Factor Substitution and Induced Innovation in North American Kraft Pulping: 1914-1940. Explorations in Economic History, Vol.24, pp.197-217.

de Janvry, A. Sadoulet, E. and Fafchamps, M. (1987). Agrarian Structure, Technological Innovations and the State, Working Paper No. 442, Department of Agricultural and Resource Economics, University of California, Berkeley.

_________________________(1988). The Optimum Bias of Technological Innovations in the Context of Transactions Costs and Lobbying, Paper for Presentation in the Symposium on Induced Innovation Theory and Agricultural Development in LDCs, American Agricultural Economics Association Meetings, Knoxville, Tennessee, August 2nd.

Fare, R., Grabowski, R. and Yoon, B.J. (1984). An Alternative View of Production and Technical Change in Agriculture: Weak Disposability of Inputs, Journal of the Developing Areas, Vol.18, January, pp.227-246.

Grabowski, R. and Sanchez, O. (1987). Technological Change in Mexican Agriculture, Social and Economic Studies, Vol.36, No.2, pp.187-205.

Grabowski, R. and Sivan, D. (1983). The Direction of Technological Change in Taiwanese Agriculture, The Developing Economies, September, pp.234-243.

Grabowski, R., Sivan, D. and Tracy, K. (1986). Technical Change in Taiwanese Agriculture, Indian Economic Review, Vol.XXI, No.1, pp.41-49.

Heng, T.M. (1985). Technical Change, Elasticity of Factor Substitution, and Returns to Scale in Singapore Manufacturing Industries, The Singapore Economic Review, Vol.XXX, No.2, October, pp.36-56.

Hunt, L.C. (1986). Energy and Capital: Substitutes or Complements? A Note on the Importance of Testing for Non-Neutral Technical Progress, Applied Economics, Vol.18, pp.729-735.

Martinello, F. (1987). Substitution, Technical Change, and the Returns to Scale in British Columbian Wood Products Industries, Applied Economics, Vol.19, pp.483-496.

May, J.D. and Denny, M. (1979). Factor-Augmenting Technical Progress and Productivity in U.S. Manufacturing, International Economic Review, Vol.20, No.3, October, pp.759-774.

Mountain, D.C. (1986). Economies of Scale versus Technological Change: An Aggregate Production Function for Switzerland, The Review of Economics and Statistics, Vol. LXVII, No.4, November, pp.707-711.

Nelson, R.A. (1986). Capital Vintage, Time Trends and Technical Change in the Electric Power Industry, Southern Economic Journal, Vol.53, No.2, October, pp.315-332.

Offutt, S. and Shoemaker, R. (1987). Government Intervention in a Declining Sector: The Case of American Agriculture, ERS, USDA, Washington.

Peterson, W. and Kislev, Y. (1986). The Cotton Harvester in Retrospect: Labour Displacement or Replacement, Journal of Economic History, Vol. XLVI, No.1, March, pp.199-216.

Shoemaker, R. (1988). The Relative Demand for Inputs: a Decomposition Analysis of U.S. Agricultural Production, Applied Economics, Vol.20, pp.665-678.

Turnovsky, M., Folie, M. and Ulph, A. (1982). Factor Substitutability in Australian Manufacturing with Emphasis on Energy Inputs, The Economic Record, March, pp.61-72.

Woolfe, A.G. (1984). Electricity, Productivity and Labour Saving: American Manufacturing, 1900-1929. Explorations in Economic History, Vol.21, pp.176-191.