H. Rutten

Onderzoekverslag 45

TECHNICAL CHANGE IN AGRICULTURE

A REVIEW OF ECONOMIC LITERATURE, WITH SPECIAL REFERENCE TO THE ROLE OF PRICES

February 1989

Landbouw-Economisch Instituut
Afdeling Algemeen Economisch Onderzoek en Statistiek

Agricultural Economics Research Institute LEI
General Economics and Statistics Division

ABSTRACT/REFERAAT

TECHNICAL CHANGE IN AGRICULTURE; A REVIEW OF ECONOMIC LITERATURE WITH SPECIAL REFERENCE TO THE ROLE OF PRICES
Rutten, H.
The Hague, Agricultural Economics Research Institute LEI, 1989
Onderzoekverslag 45 (Research Report 45)
ISBN 90-5242-018-1
145 p., tab., fig., lit., bibl.

Technical change is of great importance to the socio-economic performances in agriculture. Without the continuous introduction new techniques and methods of production, agriculture would have been very different from what it is today. Nevertheless, the forces fueling the generation and dissemination of these new techniques and methods are still poorly understood. This has, among other things, adversely affected attempts by agricultural economists to predict the relation between prices and supply of agricultural products on the longer term.

In many analyses, technical change is being treated as an one-dimensional and well outlined phenomenon. A better understanding of the process of technical change requires an approach by which one would be able to integrate the complexity of economic, institutional, historical and scientific influences.

Technical change/Economic theory/Agricultural economics/Institutional theory/Productivity change/Production function/Factor prices/Agricultural research/Price policy/Price elasticity

TECHNISCHE ONTWIKKELING IN DE LANDBOUW; EEN LITERATUURSTUDIE, MET SPECIALE AANDACHT VOOR DE ROL VAN PRIJZEN

Technische ontwikkelingen zijn van grote betekenis voor de sociaal-economische prestaties van de landbouw. Zonder het voortdurend ter beschikking komen van nieuwe technieken en methoden van produceren zou de landbouw er heel anders uit hebben gezien. Desondanks bestaat er nog maar weinig begrip van de krachten die invloed uitoefenen op het ontstaan en de verspreiding van die nieuwe technieken en methoden. Dit wreekt zich onder andere bij pogingen van landbouweconomen om het verband tussen prijzen en het aanbod van landbouwprodukten op de langere termijn te voorspellen. In veel analyses van technische ontwikkeling wordt het als een eendimensionaal en vast te omlijnen verschijnsel beschouwd. Een beter begrip van het proces van technische ontwikkeling vraagt om een benadering die de economische, institutionele, historische en wetenschapsdynamische invloeden kan integreren.

Technische ontwikkeling/Economische theorie/Landbouweconomie/Institutionele theorie/Produktiviteitsontwikkeling/Produktie-functie/Schaarsteverhoudingen/Landbouwkundig onderzoek/Prijs-beleid/Prijselasticiteit

CIP-GEGEVENS KONINKLIJKE BIBLIOTHEEK, DEN HAAG

Rutten, H.

Technical change in agriculture : a review of economic literature, with special reference to the role of prices.
- The Hague : Agricultural Economics Research Institute.
- (Research report / Agricultural Economics Research Institute ; 45)
ISBN 90-5242-018-1
SISO 631.5 UDC 631.16 NUGI 835
Trefw.: landbouweconomie.

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Landbouw-Economisch Instituut (LEI-DLO), Informatiecentrum (K.1.15)
Burg. Patijnlaan 19; Postbus 29703, 2502 LS den Haag. Tel. 070-3308134

* UITLEENBON * Verzoeke deze bon bij de publikatie te houden

Boeknummer: L28 - 45 **Vervaldatum: 05/02/98**

Titel. Technical change in agriculture : a review of economic literature, with special reference to the role of prices

Auteur / H. Rutten ; General Economics and Statistics Division of the Agricultural Economics Research Institute LEI.

Lener:

Bremmer, J.
2e etage

Preface

The effectiveness of agricultural policies in terms of productivity growth and income protection is often affected by technical changes. Whereas the influence of the introduction and diffusion of new techniques has received much attention in agricultural economic and sociological research, it is still not quite clear which factors account for these technical changes. Farm prices undoubtedly play a significant role, but economists are in disagreement about a more precise assessment of this influence. Consequently, discussions about the possibilities and limitations of price policies with regard to market control are surrounded by many uncertainties.

In an effort to contribute to these discussions the Agricultural Economics Research Department of LEI has decided to make an inquiry into the shaping forces behind technical change. By way of first exploration this research report focuses on views from agricultural and general economic literature.

The director,

J. de Veer

The Hague, February 1989

Summary

The influence of ongoing technical changes in agriculture on the volume of production, productivity performance, and economic returns can hardly be overestimated. Since World War II the use of new techniques and methods of production has given rise to unprecedented growth figures in western agriculture. In due course, however, these developments have put more and more pressure on agricultural markets and agricultural support policies.

Next to its often ambiguous effects on environment and social conditions in rural areas, the aspects mentioned above have given rise to critical reassessments of technical change in agriculture. For example, it has become important to determine the reciprocal influence of prices on technical change in order to decide upon future price policies. These assessments, however, refer to the effects, as well as to the causes of technical change. And as far as economic theory is concerned, the latter in particular present serious analytical problems.

Developments within general economic theory

A review of general economic literature on technical change reveals that these analytical problems arise already at the stage of defining the relevant concepts and issues, such as invention, innovation, technology and the measurement of technical change. Generally speaking, economists find it difficult to grasp the complexity and multiformity of phenomena which are - often for the sake of convenience - classified under "technical change". To a certain extent, this may explain why the process of invention and innovation has been treated as a "black box" for a considerable time, especially from the end of the 19th century until approximately 1930. Although the gradual eradication of this black-box approach started with the writings of Schumpeter and Hicks, it was not until the first attempts were made to quantify the sources of productivity growth for the economy at large, that the approach became more and more explicitly rebuked.

In their search for more thorough explanations of technical change, some economists tended to stress demand or market variables, while others argued for more exogeneity (e.g., by emphasizing the relative autonomy of science and technology). This eventually culminated in the "demand-pull versus technology-push" debate among economists and related scholars.

The so-called evolutionary approach can be considered as an attempt to settle this debate by introducing concepts which are designed to deal with the relatedness between economy and technology, as well as with the variety of (scientific, technological, economic, institutional, etc) factors affecting the strategies involved in the innovative process.

Explaining technical change in agriculture

The treatment of technical change by agricultural economists has, by and large, developed similar to that in general economic theory. The most advanced attempt to explain the generation and dissemination of new techniques in agriculture is, without doubt, the so-called Induced Innovation Hypothesis of Hayami and Ruttan. This still tentative theory incorporates many components of thought by other agricultural economists and has by now become a more or less generally accepted approach. Nonetheless, its arguments with regard to the generation of new techniques is one of the most criticized elements of the induced innovation approach. Furthermore, the rather heavy reliance upon the market as selective device has been criticized; on the one hand by those who prefer to stress the autonomy of technology, technology-producers and/or physical exigencies, and on the other hand by those who claim that the innovative process is induced by more than the economic factors suggested in the Induced Innovation Hypothesis, but also by different, and far more complex mechanisms. It is argued that the factors underlying the generation, i.e., the production, of (new) agricultural technologies, are still not well understood and that more attention should be given to the strategies, criteria, and selection environment of technology producing public and private institutions.

Prices and technical change in agriculture

An illustration of this state of the art within agricultural economics are the many rather unsuccessful attempts to determine the relationship between farm prices, supply and technical change quantitatively. In spite of this, this problem is often addressed by means of the price elasticity of supply; and although this instrument does produce some useful insights, it is a far too one-sided tool for this purpose. In the absence of better techniques and a better understanding of the problem, however, economists still have to make do with it.

Thus, the research agenda of agricultural economists is in need of some additions and in this respect the most recent developments within general economic theory could well serve as a point of departure. Particularly, more empirical research of the evolution of technological paradigms and trajectories in agriculture seems a promising research line to follow.

Samenvatting

De invloed van de voortdurende technische veranderingen in de landbouw op het produktievolume, de produktiviteitsontwikkeling en de economische opbrengsten, kan nauwelijks overschat worden. Na de Tweede Wereldoorlog maakten nieuwe technieken en produktiemethoden het mogelijk dat de Westerse landbouw een ongekende groei doormaakte. Van lieverlee zijn de landbouwmarkten en het ondersteuningsbeleid voor de landbouw door deze ontwikkelingen evenwel onder steeds meer druk komen te staan.

Naast het veelal tweeslachtige effect van technische ontwikkeling op natuur en milieu en de werk- en leefomstandigheden in plattelandsgebieden, hebben de bovenstaande aspecten aanleiding gegeven tot herwaarderingen van technische veranderingen in de landbouw. Zo is het des te belangrijker geworden om te kunnen bepalen wat het wederzijdse verband is tussen prijzen en technische ontwikkeling, zodat de vaststelling van het toekomstige prijsbeleid met iets minder onzekerheden omgeven kan worden. Deze herwaarderingen gaan echter niet alleen om de effecten van technische verandering, maar ook om de oorzaken ervan. En voor zover het de economische theorie betreft levert de analyse van vooral het laatste type van herwaardering vaak grote problemen op.

Ontwikkelingen in de algemene economische theorie

Een overzicht van de algemene economische literatuur laat zien dat deze analytische problemen al opdoemen bij het definiëren van de relevante concepten en vraagstukken zoals inventie, innovatie, technologie en de meting van technische ontwikkeling. Over het algemeen blijkt het voor economen nogal moeilijk te zijn om grip te krijgen op de ingewikkeldheid en veelvormigheid van die verschijnselen die - vaak vooral voor het gemak - gegroepeerd worden onder het hoofdje "technische verandering". Dit verklaart wellicht ook in zekere mate waarom het proces van inventie en innovatie zo lang, vooral tussen het eind van de 19e eeuw en ongeveer 1930, als een "black box" werd beschouwd. Alhoewel de geleidelijke uitbanning van deze benadering begon met (onder anderen) Schumpeter en Hicks, waren het de eerste (weinig succesvolle) pogingen om de bronnen van economische groei kwantitatief vast te stellen die de doorslag gaven.

In hun pogingen om een meer omvattende verklaring te vinden voor technische veranderingen, heeft een aantal economen vooral de nadruk gelegd op vraag- en marktvariabelen, terwijl andere juist meer veel meer belang hechtten aan exogene variabelen oftewel aan de relatieve autonomie van wetenschap en technologie. Deze twee standpunten vertegenwoordigen de extremen in wat onder economen en verwante wetenschappers van lieverlee het "demand-pull versus technology-push" debat is gaan heten.

De zogeheten evolutionaire benadering kan worden beschouwd als een poging dit debat te beslechten. In deze benadering worden concepten geïntroduceerd die uitgaan van zowel het verband tussen economie en technologie, als de variëteit aan (wetenschappelijke, technologische, economische, institutionele, etc.) factoren die van invloed zijn op strategieën rond inventie en innovatie.

Verklaringen voor technische ontwikkeling in de landbouw

De opvattingen van landbouweconomen over technische verandering hebben zich goeddeels hetzelfde ontwikkeld als die van de algemene economen. De meest geavanceerde poging om een verklaring te geven van de produktie en verspreiding van nieuwe technieken in de landbouw, is ongetwijfeld de zogeheten Hypothese van de Geinduceerde Innovatie zoals die door Hayami en Ruttan is uitgewerkt. Deze nog tentatieve theorie draagt een groot deel van het gedachtengoed van collega-economen in zich en is nu een min of meer algemeen aanvaarde benadering. Dat neemt echter niet weg dat er geen kritiek (meer) op is; vooral de verklarende waarde voor de produktie van nieuwe technieken wordt sterk in twijfel getrokken. Ook de nogal sterke nadruk die de theorie legt op de invloed van marktvariabelen heeft veel kritiek ondervonden. Deze kritiek komt aan de ene kant van hen die de autonomie van technologie, technologie-producenten en/of fysische randvoorwaarden meer op de voorgrond willen zetten. Aan de andere kant wordt de kritiek ook verwoord door hen die menen dat het innovatieve proces niet alleen het resultaat is van meer factoren dan de economische die Hayami en Ruttan noemen, maar ook door andere, meer ingewikkelde mechanismen vorm krijgt.

Beargumenteerd wordt dan ook dat de factoren die ten grondslag liggen aan de produktie of het beschikbaar komen van (nieuwe) agrarische technologieën nog steeds niet voldoende wordt begrepen en dat meer aandacht zou moeten worden geschonken aan de strategieën, de criteria en de selectie-omgeving van producerende (publieke en private) instituties.

Prijzen en technische verandering in de landbouw

Dat de oorzaken van technische ontwikkeling nog onvoldoende begrepen wordt wreekt zich bij de vele nogal weinig succesvolle pogingen om het verband tussen landbouwprijzen, aanbod en technische ontwikkeling langs kwantitatieve weg te bepalen. Toch wordt dit probleem veelal benaderd met behulp van de prijselasticiteit van het aanbod, een instrument dat weliswaar waardevolle inzichten op kan leveren, maar voor dit doel te beperkt is. Bij gebrek aan betere technieken en aan beter begrip van de materie, zullen landbouweconomen het er voorlopig mee moeten doen.

Algemene conclusie

De onderzoeksagenda behoeft dus enige aanvulling en wat dit betreft kunnen de recente ontwikkelingen in de algemene economische theorie goed dienen als vertrekpunt. Het zal dan in het bijzonder moeten gaan om meer empirisch onderzoek naar de evolutie van technologische paradigma's en trajecten in de landbouw.

1. Introduction

".. new technologies, processes and products have to be dreamt, argued, battled, willed, cajoled and negotiated into existence. They arise through endless rounds of conjecture, experiment, persuasion, appraisal and promotion (..) There is no unstoppable process that brings inventions to the market. They are realised only as survivors."
(Yoxen, 1983:28/29).

1.1 Background information

One of the most pronounced problems of present-day agriculture in Western economies is the combination of persisting surplus production on the one hand and persisting relatively low incomes for a majority of producers on the other. As well as being designed to circumvent this typical agricultural problem, farm policies also tend to become constantly adversely affected by this phenomenon. Thus, right from the start of a European farm policy, immanent surpluses and average income arrears constituted one of the sources of both its origin as well as its laborious progress.

Modern agriculture appears to be too successful in the sense that its expansive capacities can be said to exhibit a downward pressure on the social and economic performance of the sector itself, or at least of parts of it. Furthermore, it has put agricultural policy in most Western economies under severe financial and therefore political pressure.

"Techn(olog)ical change" undoubtedly is one of the most influential features of present-day agriculture as it has stimulated impressive productivity increases and altered and reshaped the business of farming drastically. Needless to say, there is a close relationship between technical change and surplus production, even to such an extent that the idea has taken hold of some people's minds that to solve the surplus problem effectively we have to slow down or even call a halt to technical change. Unfortunately, things are not that simple, if only because of the fact that the rising volume of agricultural production has originated from the combined effect of a growing input use and rising productivity. And to both these tendencies, technical change has contributed significantly, although not exclusively. Furthermore, technical change is influential, but on the other hand hard to pinpoint. Scholars of this omnipresent phenomenon are inclined to use terms like "a black box" and "manna from heaven", illustrating a fundamental lack of knowledge of the relationship between technical change and economic development. In addition, there is hardly any agreement on relevant subjects within the study of technical change. Consequently, we are still left with unanswered, or at best only partially answered, but selfevident questions such as:

What is technical change exactly?
How can we measure technical change?
What determines its rate and direction?
Can "society" influence its rate and direction?

1.2 The scope of this report

In this report we will not attempt to give final answers to these questions, but merely review opinions from literature on the economic aspects of technical change. Our main goal is to report the state of knowledge concerning the relationship between prices and technical change in agriculture. The motive for selecting this subject is given by the actual problems of agricultural policy, since there are broadly speaking two ways to relieve its financial burden: firstly, by reducing price-supports, and secondly by controlling the growth of production through more or less regulatory measures. The policy followed at present tries to do both, thereby assuming that lower prices ultimately will affect production negatively.

From a theoretical point of view it goes without saying that prices have to be considered as a major instrument in manipulating the volume of production, although their effectiveness in many cases leaves much to be desired. For example, in an OECD report (1984) on farm policy one can read the typical argument:

> *"It is essential that in this way (i.e., through reduction of real guaranteed prices; HR) producers find a clear signal of the situation to which they have to adopt their decisions. However, it is difficult to find a balance between a sharp price reduction --which may be politically unacceptable because of its effects on income, and economically damaging if it is beyond the adjustment capacity of agriculture - (and) on the other hand a small reduction -(which) may not succeed if its effects are offset by higher productivity due to technological progress.*

The bold statement of the American economist Cochrane that "it is wrong, as wrong can be, to conclude that a falling farm price level will reduce total farm output" merely adds to this view, and indicates extensive disagreement among economists or at best serious doubts with regards to the applicability of "pure" theory to practice (Cochrane 1958:51).

Irrespective of how one may think of the interaction between prices and production, there is at least one point of view nobody, including Cochrane, would contradict, namely that there is indeed a point at which a further lowering of prices will cut back production effectively. Of course, opinions diverge on the exact location of this "point", but it is characteristic to the matter, that most people, like the OECD, hasten to add that the social and economic consequences of such low prices would be unacceptable. With moderate price decreases, the short-term effect on supply is far less clear and at best unsatisfactorily small. This is why measures aimed directly at reducing production have been introduced in a number of cases. The unpredictability becomes even worse however, when the longer term is taken into consideration. For then, the phenomenon of technical change appears to blur supply analyses significantly; although it is common knowledge that this technical change is one of the factors that "somewhere" and "somehow" stands between prices and supply, the precise hows and whys are largely unknown. As illustrated by the leading quotation of this chapter, this lack of understanding causes repercussions on the efficacy of farm policies. This applies all the more when we speculate on what biotechnological innovations may bring and - more important in this respect - under which economic circumstances this alleged new green revolution will flourish best.

Next to its direct implications for agricultural policy, the poor understanding of technological change by agricultural economists also forms a stumbling block to the relevancy of (agricultural) economics as a scientific discipline. Obviously, this goes for predictive models in particular, since technological change is admittedly one of the most crucial (longer-run) supply-specifying variables. E.g., in his analysis of some forecasting economic studies of the Agricultural Economics Research Institute (LEI) during the sixties, Oskam (1985) found that the rate of technological change (in terms of rising labour productivity) had been underestimated by 50%. According to Oskam, this was one of the reasons why the outcomes of the studies did not correspond to the realized figures. Although technical change has received more and more attention in the course of the years, it still remains to be seen whether modern forecasting studies succeed better in incorporating this moving force than the more old-fashioned studies.

1.3 Global structure

The global structure of this report moves from the general to the specific. Thus, we will start with some definitional and conceptual problems, followed by a very rough sketch of the extensive debates among general economists on the degree of endogeneity of technical change (chapter 2). Next, we will deal with the economic aspects of technical change in agriculture, that is, with the writings of agricultural economists and related scholars on the measurement and explanation of technical change (chapter 3). A separate chapter (4) is reserved for the "initiation" of technical change in agriculture, in which the role of public and private bodies is considered. Only then can we discuss our main subject: prices and technical change. In this chapter (5) relevant pieces from the previous chapters will be summarized and discussed, that is, as far as the interaction between prices and technical change is concerned. Finally, we will try to formulate some over-all conclusions, and suggestions for supplementary research (chapter 6).

Serving primarily as a review of relevant literature on this subject, the choice was made to present the numerous views in a rather straight fashion. That is to say, next to describing these views, they are often also substantiated by quotations. Although this may hamper the readability, we preferred to convey some authenticity in this report, as well as to make these descriptions easily verifiable.

Last but not least, we should note that this study is predominantly concerned with the causes of technical change, rather than with its effects. The latter would require a separate study, and the scope of our analysis primarily calls for a quite one-sided focusing of our attention on the economic forces behind technical change.

In addition, it should be noted that this report is above all a desk study and is intended to form the basis of more detailed empirical research of which some examples will be given in the final chapter.

2. Economic theory and technical change

"To measure is not to understand"
(W.E.G. Salter)

2.1 Introduction

In this chapter we will briefly review the ways in which the phenomenon of technical change has been and is being treated by general economic theory. We will demonstrate the manifold problems mainstream economic theory has met - and still meets - in its efforts to cope with the role of changing techniques and technologies in economic life. In subsequent chapters we will concentrate primarily on a distinct field within economic theory, that is, agricultural economics. The very fact, however, of agricultural economics being an applied science, forces us to start from the general scope of analysis.

2.2 Definitions of techn(olog)ical change

The American economist W.W. Cochrane has used a seemingly very simple definition of technical or technological change. To him it is,

> *"..an increase in output per unit of input resulting from a new organization, or configuration, of inputs where a new and more productive production function is involved."* (Cochrane, 1958:46).

This definition may have been quite appropriate for Cochrane's purposes - after all he was not very interested in the exact causes of technical change - but when we concentrate on what technical change actually signifies, this definition is rather restricted 1). On reflection, there appears to be a wide varity of definitions.

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1) Among others, Dale, E. Hathaway pointed at the "somewhat circular" explanations following from this definition, since it seems to identify technical change with productivity growth. In Hathaway's view, conversely, "new technologies" constitute only one out of several output increasing factors (such as specialization and economies of scale) (Hathaway, 1963:95). It should be noted however, that Cochrane does not lump together technical change and productivity change, as the former will always be expressed in the latter, but not necessarily the other way around.

2.2.1 Technical and technological change

To begin with, technical change cannot be identified completely with technological change. Usually, technology - literally the theory of technique - is referred to as "..the body or stock of techniques, procedures, or ways of ordering economic activity." (Metcalf, 1970:60) Or as "society's pool of knowledge regarding the industrial arts" (Mansfield, 1968:10). Technique is commonly defined as "the utilized method of production" (ibidem:11). Thus, technical change can be conceived as the addition of a technique to the stock of techniques already in use. Technological change would then refer to changes in the pool of knowledge, or - more limited - in the stock of potentially viable techniques.

A more precise definition of technical change is suggested by Binswanger. According to him, it should be defined as:

> *"...changes in techniques of production at the firm or industry level that result both from research and development and from engineering, or agronomic principles to techniques of production across a broad spectrum of economic activity."* (Binswanger and Ruttan, 1978:18/19).

In other words, Binswanger places more emphasis on the application of (changed) knowledge. A different and more confusing set of definitions can be found in De Groof, according to whom technique is "the collection of ordered partial actions directed to the production of a good or collection of goods." And technology is "all the techniques which are applicable in one way or another." (De Groof, 1977:7; my translation,HR) These two definitions are rather confusing because of their vagueness - for example "partial actions" and "applicable" - and because they completely neglect the relevance of increased knowledge. Nonetheless, Koolschijn (1970), who claims to use the same definitions as De Groof, holds the position that "the concept of technical development deals at first with the increase of knowledge, that is, technology" 1).

In conclusion we could say that technical change is to be understood as the addition (or subtraction) of one or more techniques in relation to the existing ones in use, whereas technological change refers to changes in the quantity or quality of potential techniques.

2.2.2 Invention and innovation

A further distinction concerns the issue of invention versus innovation. According to Roobeek "an invention is the putting in-

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1) Cf. Nordhaus (1969:4-7) who extended this definition by distinguishing between 'general' and 'technical' knowledge.

to operation of technical and scientific knowledge, an idea for or an outline of a new product, process or system" (Roobeek, 1984:16/17; my accentuation and translation, HR).

And Enos defined invention likewise, namely as "..the earliest conception of the product in substantially its commercial form", and innovation logically as "the first commercial application or sale". (Cited in Rosenberg, 1976:70) In this context, innovations are often subdivided into "basic" innovations and "second-generation" or improvement innovations 1).

Jacob Schmookler, who has put the economic relevance of inventions to the attention of every economist, defined ("every") invention as "a combination of pre-existing knowledge which satisfies some want" (Schmookler 1966:10). In his view, innovation is the act of "making" a certain technical change by a producer. It was Schumpeter who pointed at the effect of innovation in theoretical terms and even defined the concepts in these terms by calling it:

> *"..that kind of change arising from within the system which so displaces its equilibrium point that the new one cannot be reached from the old one by infinitessimal steps."*
> (Cited in Elster, 1983:100).

Yet, as Koolschijn and others stated, it is too simple to conceive technical or technological change as proceeding from invention to innovation in a linear fashion:

> *"In some cases it is the other way around. More and more, the innovation sets the contours for Research and Development. That way, 'innovation' breeds 'invention'."*
> (Koolschijn, 1970:15;my translation,HR).

Rosenberg has also criticized this "Schumpetarian heritage". In his view the rather strict distinction between invention and innovation resulted in the economist's neglect of the economic importance of the process of invention: whereas innovation is by definition connected with commercial application, its "origin" is merely regarded as belonging to the spheres of scientific knowl-

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1) Likewise, we can distinguish 'basic' and 'applied' research: "If basic knowledge is static, applied research is subject to the principle of diminishing returns and will eventually come to a halt as the costs of successive technical innovations within the existing knowledge boundary rises." (Arndt and Ruttan, 1977:11).

edge, not to those of economics (Rosenberg, 1976: chapter 4) 1). Nevertheless, many authors prefer to use the unilinear conception as mode of thinking.

Perhaps this controversy is primarily caused by the economists' inclination to fence in their scientific domain. For example, Schumpeter's phrase "from within the system" indeed suggests that this system can be defined properly, first and foremost through its boundaries. Analogous to this phrase are the more common terms *endogenous* and *exogenous*: both terms presuppose the existence of systems within or next to (other) systems. In fact, Rosenberg's comments and those made by others reflect doubts as to the location or even the relevance of these lines of demarcation. We will return to this matter explicitly in chapter 3, for then primary agriculture will be presented as one of these "systems".

Leaving aside these definition problems, we should also point at a further breakdown of innovation into several types. Whereas the distinction between *product* and *process* innovations will be dealt with at more length in chapter 3, we will limit ourselves to the popular antipodes *radical* (or *basic*) and incremental innovations (Coombs et al, 1987:5). Radical innovations by definition imply some sort of break-through with regard to the existing assortment of consumer goods or the existing techniques and methods of production. Incremental innovations are often much less tangible and mostly come down to improvements upon current techniques, methods or products. It obviously is quite arbitrary to determine in which of these categories an innovation is to be located.

2.2.3 The shift-thesis

A final confusion with respect to definition matters concerns the often made identification of technological change with a shift of the production function. See for instance Cochrane's definition at the beginning of this chapter. Ruttan similarly proposed to define technological change in terms of a movement of the production function, i.e., as:

> *"..changes in the coefficients of a function relating inputs to outputs resulting from the practical application of inno-*

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1) To which Rosenberg added that this practice also has led to pooh-pooh the economic importance of engineering activities and - in general - modifications of inventions (Ibidem: 66-67). See for example Snodgrass and Wallace (1975:122), who boldly stated that "..invention is only the scientific fact - innovations the economic fact that determines which inventions are used and which are not".

vations in technology and in economic organization."
(Ruttan, 1959:606) 1).

With this definition he merely specified Schumpeter's contention that because it may be impossible to decompose technical change in "infinitessimal" steps, one can regard any shift of the production function as an expression of technical change. A typical graphic expression of the shift-thesis is presented in figure 2.1, where the shifting of the original isoquant I to point C implies neutral technical change in the sense that it is not accompanied by a changed capital/labour ratio. A shift inward to point A or point B signifies non-neutral technical change: labour-saving in the first, and capital-saving in the second case.

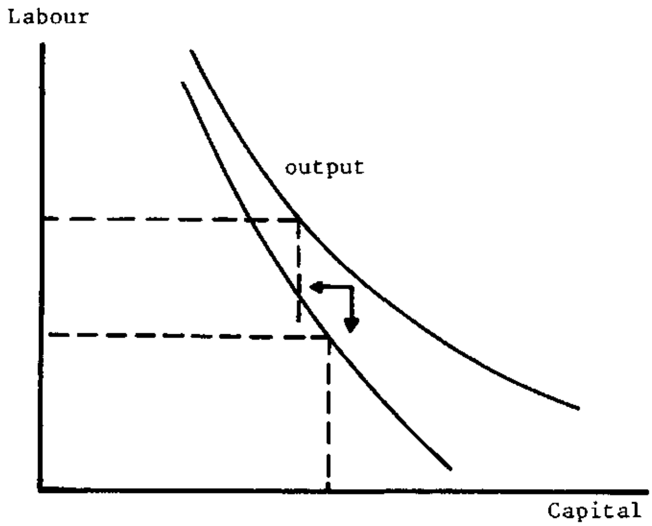

Figure 2.1 An illustration of the shift-thesis
Source: Link (1987:9).

Among others, Heertje (1973) criticized this practice because of its constraints: the shift-thesis can only be applied to changes of (parameters of) the old production function, not to the creation of a completely new production function:

"Generally, the extension of technical knowledge and the creation of new technical possibilities, cannot be pushed into the shackles of a shifting production function."
(Ibidem:168/169;my translation,HR).

1) Cf. M. Brown (1966/39).

Or, in more practical terms, technical change might involve a completely new set of both inputs and outputs, reason why any comparison between the old and the new situation in terms of a shifting production function is seriously obscured. In less extreme cases, the problem arises as to whether and to what extent the new situation is the result of a new choice of existing techniques (a movement along the curve) or of a change in the number and quality of available techniques (a shift of the curve). As Kaldor has stated:

> *"The rate of the shift of the curve will itself depend on the speed of the movement along the curve, which makes any attempt to isolate the one from the other the more nonsensical."*
> (Cited in Koolschijn, 1970:23).

For instance, the intensification of the use of a certain factor, may consist of both "pure" factor substitution and of "pure" intensification 1).

T.W. Schultz (1964) is also one of the authors who criticized the mere identification of a shifting production function with technical change as an oversimplified treatment of technical change. This would, in his view, boil down to looking upon technical change as having nothing to do with economic processes, since the causes of the shifting itself, contrary to the "movement along", can be ignored without doing any harm to the line of reasoning. We only need to refer to figure 2.1 to show his point: the shifting of the curves is something that just "happens" to the economy or the firm and the mere economic content of this event is that it affects the use of production factors 2).

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1) Pasinetti: "When we come to actual observations, comparisons become somewhat mor restricted, because what we can observe are not entire production functions but only actual combinations of factors. In the traditional framework this means we have no unique way of distinguishing between a *change* of the production function and a *movement* along the same production function." (Pasinetti, 1959:271-272).

2) Cf. Amendola and Gaffard (1988:21): "Technical change (...) has the nature of a quantitative adjustment, and is brought about by a simple and analytically instantaneous shift of resources which makes it possible to define automatically the new productive capacity to be compared with the old one, characterized by a different combination of the same resources."

2.2.4 A formal recapitulation

As becomes clear already at the stage of definitions, technological or technical change turns out to be a tricky subject for theoretical treatment. Most of the concepts and conceptions involved appear to be closely related to each other. For the sake of convenience, we have constructed a small scheme in which some options for definitions and implications are presented (figure 2.2).

Change in:	Option: 1	2	3	4
Pool of knowledge?	NO	NO	YES	YES
Utilized method of production? 1)	YES	NO	NO	YES
Invention	-	-	+	+
Innovation	+	-	-	+
Technological change	-	-	+	+
Technical change	+	-	-	+

Figure 2.2 Options for definitions

Thus, when the pool of knowledge remains the same and there is only a change in the method of production (option 1), inventions - by definition - cannot take place, and we cannot speak of technological change. Innovations and technical change, though, may occur. The second option is of no interest here: none of the four definitions apply. The third option obviously is the reverse of the first, while the fourth covers all definitions. Evidently, this scheme assumes a certain span of time in which changes take place: option 4 will require a greater span of time, whereas the other two relevant options will probably apply to the more short-term situations. A similar remark can be made with regard to the relevant geographical area. But there are more reasons to put the validity of this scheme in the right perspective. For instance, the assessment of whether knowledge has changed substantially enough to grant the label technological change, will often be very arbitrary 2). Furthermore, this set of definitions assumes

1) Uhlin (1985:75) suggested the respective terms 'state of art' versus 'state of use'.

2) For that reason Nordhaus (1969:65 a.f.) distinguished between "new knowledge" (i.e., "true discovery of knowledge not previously in society's knowledge pool") and "redundant knowledge" (i.e., "the uncovering of what is already society's knowledge pool").

that inventions can only take place when technical knowledge or - in the literal meaning - technology has changed. In view of the definitions given earlier, this need not be the case.

Notwithstanding these comments, a general line of thinking can be developed. Thus, we can conclude by stating that in principle, with reference to figure 2.2, (1) technological change and invention precede technical change and innovation, and (2) technical change tends to alter the existing relations of input to output as well as the structure of input to such an extent that a completely new set of productive determinants emerges.

Hereby we join the perception of Myers and Marquis, who pictured the process of innovation in the following, albeit rather uni-linear, fashion:

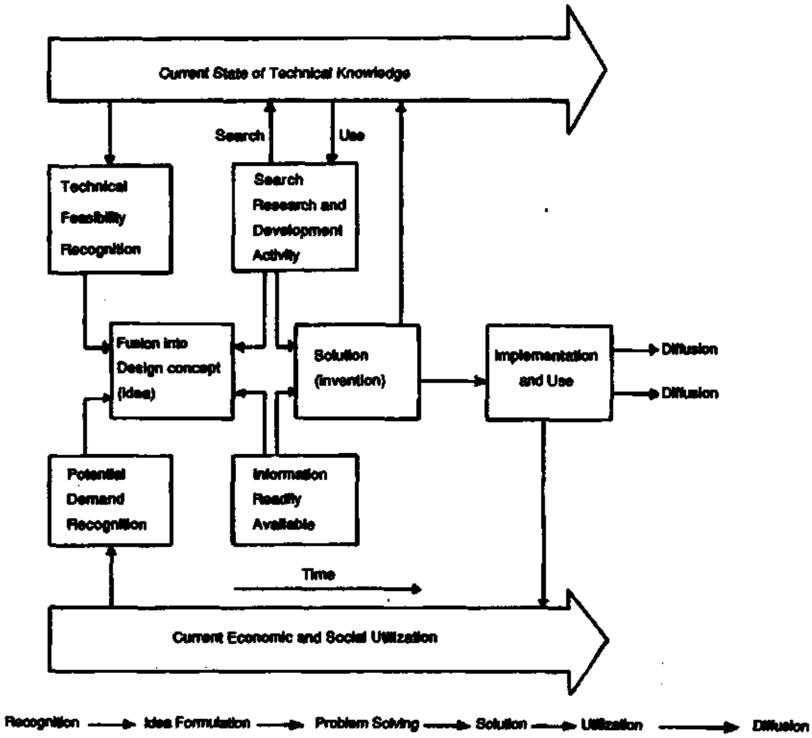

Figure 2.3 Elements of the innovative process
Source: L.A. Brown, 1981.

Obviously, some conceptual flexibility seems a conditio sine qua non for any fruitful treatment of our subject. In the following we will - except when stated otherwise - define both technical and technological change as the becoming available of new techniques and methods of production. Thereby we assume that a change in the pool of knowledge is likely to ultimately lead to its implementation in the form of applied new techniques and methods of production, although a large percentage of all inventions and even of innovations will never reach the stage of successful commercial maturity. This enables us to use the term "technical change" as a common denominator 1).

2.3 Technical change: from manna from heaven to subject of research

Although the influence of both technological and technical change on economic performances has become more and more important over the years, the attention it has received in economic science does not seem to reflect this trend. Far into the 20th century, technical change was considered as exogenous to the economic system. That is to say, according to the most common approach as laid down, e.g., in the mainstream handbooks on economic theory, technical change was often - and sometimes still is - presented as an external affair.

In this paragraph we will try to give a very short outline of the history of economic thinking on technical change. Firstly, we will deal with some "classics" of which Schumpeter is the last in line. Next, when dealing with the degree of endogeneity of technical change, we will pay attention to some more modern approaches.

2.3.1 A short history of economic theory: classical economists

Many outstanding economists of the eighteenth and nineteenth century emphasized the vital contributions of augmenting knowledge and skills to the productive capacity of an economy. Thus, one of the founders of classical political economy, Adam Smith (1979) stressed the importance of division of labour through continuous specialization, not only at the micro-economic level, but also in sectoral and geographical terms 2).

By means of his famous example of the production of pins, Smith illustrated his view on the necessity of an extended division of labour:

> *"..a workman not educated to this business (..), not acquainted with the use of the machinery employed in it (to*

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1) Among others, Peterson and Hayami (1977:500) employed the same approach.

2) Pavitt (1985:371), while dealing with 'sectoral patterns of technical change' even sighs: "Perhaps (Adam Smith's) is a tradition to which we should return."

the invention of which the same division of labour has probably given occasion), could scarce (..) make one pin a day, and certainly could not make twenty. But in the way in which this business is now carried on, not only the whole work is a peculiar trade, but it is divided into a number of branches, of which the greater part are likewise peculiar trades."
(Smith, 1979:110; my accentuation, HR).

As we can deduce from this passage, the attractive feature of Smith's theory is that he conceived technical change primarily as organizational improvements, rather than as new capital goods or new techniques per se 1). For it is only in the presence of (enhanced) division of labour, that labour productivity can be increased through higher skills, time-saving, and "the invention of a great number of machines which facilitate and abridge labour, and enable one man to do the work of many" (Ibidem: 112-114).

Interestingly enough, Smith made a point of the differences between agriculture and manufacturing. That is, because of the limited possibilities of division of labour in agriculture, he considered technical change in agriculture to be limited: labour productivity - or, in Smith's terms, the "productive powers of labour" - would not rise as fast as in industry. Smith added to this argument that the degree of labour specialization is determined by the size of the market. Thus, because of the lower income elasticity of agricultural relative to industrial products, specialization in agriculture is also limited by the market.

The works of David Ricardo attract our attention because of the many passages on (the introduction of) machines in the labour process. In the chapter On Machinery of his "Principles", Ricardo wrote:

"Machinery and labour are in constant competition, and the former can frequently not be employed until (the cost of;HR) labour rises."
(Cited in Heertje, 1973:20).

Two propositions can be derived from this short passage. First, the proposition which has later become known as the "Ricardo effect", stating that, at a given state of technique, changing price relations between capital and labour (for example labour becoming expensive relative to machinery) will give rise

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1) Cf. Deane, who stated: : ".. in Smith's theory techical progress was associated not primarily with new machinery, or new processes, or new products, but with the improvements in the organization and equipment of the labour force due to specialization." (Deane, 1978:12).

to a substitution of the one factor by the other (for example machines replacing or saving manpower) 1).

Secondly, in the above mentioned framework, "new" or in any case "better" machines serve as an important weapon in the ever present competition.

More than Smith and Ricardo, Marx has centered technical change in his analyses of economic evolution 2). In the various volumes of Capital, Marx discusses at length both the origins and the effects of the "revolutionizing forces" of the capitalist mode of production. Technical change, according to Marx, is part of the inherent social tension of this historical mode of production: within this setting, technical change provides catalyzing and accelerating influences as well. Marx's following famous statement summarizes his view in a nutshell:

> *"At a certain stage of development, the material productive forces of society come into conflict with the existing relations of production, or - what is but a legal expression for the same thing - with the property relations within the framework of which they have operated hitherto. From forms of development of the productive forces these relations turn into their fetters. Then begins an era of social revolution. With the change of the economic foundation the entire immense superstructure is more or less rapidly transformed."* (Marx in the Preface to his "Contributions to the critique of political economy").

Like Smith, Marx considered the division of labour to be crucial to the development of the "productive forces". But he attributed more importance to the production process, for in Marx's view it is in the production process that surplus value is being created; not in the market or through market processes. The role of technical change in the production process lies primarily in its creating of "surplus labour" 3), a characteristic which applies not only to the individual firm but also to capitalist societies at large, for one of its effects is the permanent resurgence of a relative surplus-population. This way, Marx considered technical change to be one of the main mechanisms or instruments through which the structure of employment and economic sectors evolve over time. As to the origins of technical change, i.e., the "production" of new techniques, Marx emphasized the role of science, but he considered science - simply put - as a "serving-

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1) Heertje (1973:21): "The demand for labour rises along with the increase of capital, but less than proportionally". (My translation, HR).
2) Cf. Nathan Rosenberg (1982), and Heertje (1973).
3) ".. a smaller quantity of labour sets a larger quantity of capital in motion." (Marx, 1981:389).

hatch" for the needs of the capitalist society; needs, or demands, which should be viewed in the light of (the solving of) contradictions or at least tensions within the economy.

In spite of Marx's fruitful - and controversial - views, the writings of the twentieth century economist Schumpeter have had more influence on the way in which technical change was to be treated in mainstream economic theory. In this respect, his concept of entrepreneurship is vital, for Schumpeter's entrepreneur is the one who carries out innovations, while possessing "more than normal economic talents" (Roobeek, 1984:17) 1). According to Schumpeter, innovations can exist in five different shapes:

> "(1) The *introduction of a new good (..) or of a new* quality of a good;
> "(2) The introduction of a new method of production (..);
> (3) The opening (and/or entering;HR) of a new market (..);
> (4) The conquest of a new source of supply of raw materials or half-manufactured goods (..);
> (5) The carrying out of a new organisation of any industry, like the creation of a monopoly position (..) or the breaking up of a monopoly position."
> (Cited in Elster, 1983:116).

With regard to these five points Kennedy and Thirlwall (1972) comment that new products change the distribution of demand and affect growth (the latter through the rate of investment), that new processes give rise to new production functions, and that the latter three types of innovation can change the efficiency with which resources are employed. (Ibidem:56) In the same vein we could say that the first and the third type of innovations concern the demand-side of economic activities, whereas the other types concern the supply-side.

These five types of innovation constitute, in Schumpeter's words again, the "fundamental impulse that sets and keeps the capitalist engine in motion" (Cited in Heertje, 1973:120). Later on, Schumpeter highlighted the role of big firms and research institutes, rather than that of the entrepreneur.

In a more theoretical perspective, Schumpeter's stress on the "spontaneous and discontinuous" character of technical change

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1) Cf. Rosenberg (1982:106): "The Schumpetarian entrepreneur is a distinctly heroic figure, prepared (unlike most mortals) to venture forth boldly into the unknown. His decisions are not the outcome of precise and careful calculation, and, Schumpeter emphasized, cannot be reduced to such terms." And Elster (1983:117) on the Schumpetarian entrepreneurial motives: ".. the dream and the will to found a kingdom; the will to conquer (..); and the joy of creating, of getting things done".

is perhaps his important contribution. In Schumpeter's vision, technical change proceeds through "neue Kombinationen", that is, new combinations of factors of production which together form completely new production functions. Moreover, innovations do not only take place by means of new combinations, but in clusters as well; once a few firms have taken the first innovative steps (and when these appear to be successful), a greater number of firms follow because the original innovation has been imitated, improved upon and/or accommodated to specific circumstances. (Roobeek, 1987:26-27) The discontinuous character of technical change is primarily due to this clustering of innovations, since - as Schumpeter contended - isolated improvements not only occur seldom, but also tend to contribute far less to the productive performances of an industry or economy. These propositions serve as the basis for Schumpeter's views on economic growth in general and economic cycles in particular, subjects which have been linked to technical change by many authors before and after Schumpeter, albeit not always as thoroughly.

2.3.2 From classical to neoclassical economic theory

Schumpeter's views in fact contained a sharp criticism on the mainstream economic theory of his days, the so-called neoclassical theory. Schumpeter criticized the stress on equilibrium and he also stressed the utmost importance of the phenomenon which most "neoclassics" considered to be at best interesting, but in the end of a non-economic nature: technical change.

Neoclassical theory, the beginning of which can be dated as far back as to the second half of the 19th century, has been revised and corrected to meet criticisms like Schumpeter's several times. Major changes within the theoretical framework, however, occurred only after the thirties of this century. Since then, neoclassical theory has become the neoclassical "synthesis", indicating the incorporation of - amongst others - Keynes's ideas 1). In the following chapters, we will deal with the era after roughly 1945, but before doing so, it seems appropriate to give a broad sketch of four troublesome aspects of the treatment of technical change by neoclassical theorists.

Firstly, neoclassical theory had thus far been struggling with the incorporation of dynamic elements. In essence it was a theory about the state of economic life, rather than about its process. As a consequence, technical change was left out of the picture. Only the problem of choosing between available techniques - and consequently the movement along the production function through factor substitution - was regarded as an economic matter. With others, Schumpeter can be credited for the revisions that have later on taken place in this respect.

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1) See for example Harris (1978) and Cole et al (1983).

Secondly, technique or technology nevertheless served as a major factor in explaining the distribution of income among economic factors, since the marginal productivity of factors of production was considered to be the main determinant of their prices. So, through productivity, technical change came into the picture after all, be it through the backdoor. Neoclassical analysis usually circumvented this problem by formally departing from both given income distribution and absence of technical change.

Thirdly, J.R. Hicks paved the way for a considerable body of research by economists on the direction of technical change. The following phrase by Hicks on this subject has become famous:

> *"A change in the relative prices of factors of production is 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."*
> (Cited in Elster, 1983:101)

Hicks's view clearly represents a firm plea in favour of the existence of at least a certain degree of endogenous technical change. Although this proposition has been criticized - to which we will return later on - it is still at the heart of present-day mainstream theories on technical change.

Fourthly, there still remains a theoretical void as far as the explanation of the rate of technical change is concerned. Many studies confine themselves to measuring technical change - both its direction and rate - as adequately as possible. Obviously though, as Salter has stated, to measure is not to explain. Furthermore, as these attempts encountered numerous conceptual and statistical difficulties, it is no surprise that many authors heaved the sigh that technical change still belongs to the realm of the "black box". For example, Kennedy and Thirlwall stated in 1972:

> *"The best that can be done is to measure technical change by its effects, such as its impact on the growth of national income, or on the growth of factor productivity not accounted for by other inputs, leaving technical change as a residual."*
> (Kennedy and Thirlwall, 1972:13) 1).

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1) Cf. Freeman (1977:244): "The growth models of the 1950's and the 1960's did at least have the merit of attempting to escape from the blind alley of static equilibrium analysis, but like the rest of neoclassical economics they suffered from a failure to get grips with the actual process of science, invention, innovation and technical change."

As a rule, these measurements were based on the formal equations which originated primarily from Cobb and Douglas's theory of production, stemming from 1928. These and other efforts to measure technical change will be the subject of the next paragraph.

2.4 Modern (economic) theories of technical change

The economist Binswanger argued that a theory of endogenous technical change should provide an answer to the question: "How do economic variables affect the nature of technical change?" Obviously, stated this way, such a theory would be rather limited in its scope. For, as we have seen above, it is not only the nature or direction, but the rate of technical change which calls for an explanation as well. In "Induced Innovations", the book of which Binswanger is one of the editors, most attention is given to measurement (of direction and rate), and as far as explaining is concerned the nature of technical change indeed has been given priority. Apparently, we have to deal with four fields of research which in fact have been, or at least could be treated separately:

(A) Measuring and
(B) Explaining the
(C) Rate and
(D) Direction of technical change 1)

These four fields, however, are closely interrelated. As we have seen, the distinction between measuring and explaining has to be somewhat blurred because of the conceptual problems involved. Moreover, the rate of technical change, for example, is determined by the extent to which new techniques remove bottlenecks, whereas the nature of technical change reveals the types of bottlenecks and the way these are removed. In other words, a form of technical change which has the exclusive characteristic of saving on labour (-costs) may not be adopted rapidly by entrepreneurs when labour supply is abundant or when the price of labour is not expected to increase in the near future. Thus, there may exist a close relationship between the rate and the direction of technical change 2).

In the following paragraphs we will discuss some approaches to the measurement and explanation of the rate and direction of technical change. Before anything else though, we should dwell

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1) In chapter 2.4 we will add a fifth field of research: the diffusion of innovations.
2) Cf. Salter (1969:13): ".. factor prices change slowly but continuously through time, and this alone is sufficient to produce a constant stream of new techniques of production."

on the use of the term "productivity change", which will be used very frequently. First of all, whereas technical change can always be expressed in terms of changed productivity achievements, the latter is not necessarily caused exclusively by the former. In fact, this confronts productivity measurements with a serious problem in as far as these are meant to shed some light on the role played by technical change. We will deal with this later on. Secondly, as far as productivity change expresses technical change (and consequently the first is used as denominator for the second), it is important to chose the proper type of productivity figures. Generally speaking, partial productivity figures, for example labour productivity, are inferior to those on total factor productivity 1).

2.4.1 Production theory 2)

In the course of time, the common notion of "the state of technique", as being an extra-economic feature, encountered more and more criticism. This evolution can be illustrated by the developments within "production theory", that is, in the treatment of technical change in relation to production functions. Generally speaking, production functions are a formal representation of technical relationships within, or possibilities of the production process under given economic circumstances. It thus represents the state of technology in an entrepreneurial world; profit-maximizers are supposed to have full knowledge of the set of available (and optimal) techniques, and to be capable of switching from technique A to technique B whenever (changes in) factor-price relations urge them to do so. In case these economic conditions change, the technical characteristics may change along, but nevertheless remain the primary feature of the production function 3). Amendola and Gaffard (1988:2) presented a very neat description of this aspect of production theory:

> *"Different techniques can (..) be classified and compared on the basis of given criteria, and the problem of the choice of the technique can be structured as a typical maximization process in a context in which the choice set is given and the outcomes of the choices are known. The solution is obvious: once a technique has been defined as superior accord-*

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1) See e.g. Van den Noort (1970).

2) See also Lave (1966), Brown (1966), Heertje (1973), Nadiri (1970), Kennedy and Thirlwall (1972), and Link (1987).

3) In addition, we should note that in principle no theoretical distinction is made between the processes on the micro level (the firm), the meso level (the sector) and the macro level (the (inter-)national economy), that is, as far as analysis is concerned (Cf. Heertje, 1973).

ing to some criterion (e.g. a higher profit rate for a given wage rate) it is automatically selected, and the only problem for the economy is then to adjust its productive capacity to it. In some models (the majority), the adjustment is not even considered, and there is a jump directly to the description of the new shape of the productive capacity; in other (more recent ones) the adjustment is considered, mainly in the sense that there is an attempt to find the conditions required for convergence on the new position."

The most frequently used mathematical version of the production function, is the one developed by Cobb and Douglas. It relates output to input of labour and capital in the following manner:

$$Q=aC^{b}.L^{1-b},$$

stating linear homogeneity, or, in other words, constant returns to scale. (Where Q stands for the volume of output, C and L for capital and labour respectively (in physical quantities); a is a constant, and b is a coefficient)

This formulation made it possible to get to grips with the contribution of capital and labour to economic growth. This is sometimes called the "factor-shares" method of growth accounting (Kennedy and Thirlwall, 1972:17). However, many computations based on this formula left a considerable part of economic growth unexplained. And it was Solow, who, "..with a magnificent wave of his hand" (Lave, 1966:4), dubbed this "unexplained residual" technical change! 1). Thereupon this unexplained residual has been inserted in the formula, thus becoming,

$$Q=Tf(C,L) \quad 2),$$

in which T is a parameter for disembodied technical change, that is, the implementation of new techniques and methods of production that cannot be accounted for by changes in capital and labour.

Although empirical testing of production theory started in the thirties, it was only after roughly 1945 that these technol-

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1) Freeman (1977:244): ".. it was a rag-bag for social, managerial, structural, educational, political, psychological and technological changes other than the purely quantitative increases in the volume of labor (..) or the volume of capital (..)".

2) See Mátyás (1980), and Van den Noort (1965). Brown (1966:39): "Technical changes find expression in variations in the parameters of the production function (..). Each parameter has a particular significance so that their changes represent different types of technical progress."

ogy-inserted functions were tested at more aggregate levels. These latter estimates yielded rates of technical change ranging from 1.1% to 1.7% per year (for the U.S. economy between approximately 1850-1950). However,

> *"..what really set the field alight were the findings of Fabricant, Abromowitz and Solow that between 80% and 90% of the growth of output per head in the American economy over the previous decades could not be accounted for by increases in capital per head and must therefore be due to some form of technical progress."*
> (Kennedy and Thirlwall, 1972:17)

These growth accounting procedures encountered considerable doubts. Some argued for a more thorough unraveling of this peculiar phenomenon called technical change. Others, especially Jorgenson and Griliches (1972), argued that all these computations crudely overestimated technical change and that in fact adequate measurement of inputs would hardly leave any room at all for technical change.

Another line of thought was to treat "non-conventional" inputs as a separate variable, thereby accounting for the fact that changes in the quality of inputs (as being a main source of growth) are not "free gifts from nature", but have to be produced and effectuated somehow. We could think of activities like research and development, education and extension (Peterson and Hayami, 1977:516).

The whole dispute obviously boils down to the articulation of technical change, that is to say, the uncovering of its main elements. The contributions to the debate made by Jorgenson and Griliches are illustrative in this respect, because they tried to account for productivity growth as rigorously as possible from the point of view of production theory. Much earlier, Griliches (1963:331) had already stated that,

> *"The whole concept of the production 'function' is not very helpful if it is not a stable function, if there are very large unexplained shifts in it. Moreover, it does not further our understanding of growth to label the unexplained residual changes in output as 'technical change'."*

Elaboration of this opinion led Jorgenson and Griliches (1972) to hypothesize that "if real product and real factor input are accurately accounted for, the observed growth in total factor productivity is negligible" 1). They used the "conventional" definition of Total Factor Productivity change, namely changes in real output divided by changes in real total input. In line with this approach, a change in total factor productivity should reflect a shift of the production function, whereas a movement along the production function is reflected by changes in output and factor input without a change in total factor productivity taking place (Ibidem:250).

And indeed, the final outcome of their computations for the US private domestic economy from 1945 to 1965 left room for a change in total factor productivity of only 0.1% per year. By contrast, the "unadjusted" measurements claimed 1.6%. Jorgenson and Griliches consequently concluded that movements along the curve have by far surpassed shifts of the curve.

In paragraph 2.2.3 we have already mentioned that Kaldor considered this to be a "nonsensical" approach and that he even rejected the production function as a tool in growth analysis. Koolschijn (1970:22 a.f.) summarized his objections as follows:

1. The application of new knowledge in the production process is heavily intertwined with the putting into production of new capital goods. For example, increasing capital intensity may imply the use of new knowledge concurrently, which renders it impossible to isolate the "movement-"effect of the first from the "shift-"effect of the latter; 2)
2. The stock of capital which is available at a certain point in time reflects the extreme differentiation in time of investments. In other words, because of the constant accumulation of capital, there is no such thing as a stationary long-run equilibrium, although the curve is made up of points which presuppose this equilibrium to exist, or at least to come into existence. Consequently, we cannot speak of movements along, but of movements within the curve (of optima).

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1) Cf. Nadiri (1970:1150): "In principle, if all things are properly measured and the function governing their interactions is properly specified, then the residual (..) should be zero or nearly so." See also Walters (1963:27). All these statements are, of course, true by definition. Mansfield (1968:33) counteracted: "One can always 'explain' changes in output by changes in input (appropriately measured), but many of these changes in input must themselves be attributed to technological change. It is true, however, that technological advance is due in some part at least to inputs invested in advanced technology."

2) Cf. Rosenberg (1976:64), who adds to this: "Today's factor substitution possibilities (..), are the product of yesterday's technological explorations."

3. The state of technique cannot be measured, because there are no ways to quantify the "shift-"effect properly.

The findings of Jorgenson and Griliches have also been criticized by Denison, who argued for a different way of adjusting and by doing so obtained different results (Heertje, 1973:239) 1). According to Denison, capital-embodied technical change is heavily determined by the age-structure of the gross capital stock, a factor which he expected not to vary significantly. Therefore his calculations were only adjusted for the embodiment of technical change in labour power.

A more theoretical critique has been given by Rymes (1971), according to whom Jorgenson and Griliches "neglect(.) the fact that commodity inputs are capable of being produced with ever increasing efficiency", and that "commodities (Physical Things, which are produced by the economic system) are not primary inputs like labour and natural agents". (Ibidem:chapters 3,5,6) For that reason, Rymes claims, it is illogical to draw a distinction between the accumulation of commodity capital and technical change; after all, this accumulation - the growth of Capital - is a mere expression of enriched technical practice in the process of production.

A fictive example

As far as measurement problems are concerned, elements of the criticism can be illustrated by means of a fictive example; suppose car-drivers could buy an additive to gasoline which would make their car more energy-efficient. A great innovation, especially since the price of the additive is far less than the benefits of gasoline saved. When expressed in terms of energy used per mile, this additive will undoubtedly improve the productivity of cardriving. It would also be very easy for the statistician to compute the productivity increasing effect of the additive. But then problems arise, for in the period during which the additive becomes widely adopted, other things change as well: new and more energy efficient cars enter the market at attractive prices, people start buying a catalyst, tariffs of public transportation decline substantially, and people begin to worry more about the energy issue. In short, car driving as a business changes drastically. The statistician who at first could assuredly state that the additive caused a x% productivity increase, would now run into serious problems. He might be able to compute the over-all productivity change roughly, but uncertainty would be greater if he was asked to determine quantitatively the constituting elements of this productivity growth. For how is he to

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1) See also Maddison (1987) for a review of growth accounting methods and their outcomes.

distinguish the political, the technical and the economical changes that have taken place?

Jorgenson and Griliches would probably have addressed this problem by adjusting for all the quality changes that have occurred with regards to the gasoline, the cars and - if possible- driving habits. And if any (total factor) productivity increase would result from this method, they would only be able to attribute it to fully disembodied technical change. From the analytical point of view, this is rather dubious, and from the practical point of view clearly disappointing. Furthermore, and perhaps this is the most crucial drawback, this kind of approach gives no explanation whatsoever for technical change since it only tries to measure its effects. The generation and dissemination of new technologies (Freeman, 1977:225) are only looked upon ex-post.

Yet, at the same time, one major merit of production theory, and of Jorgenson and Griliches' approach in particular, is that it leaves room for the acknowledgment of the endogenous character of technical change 1); after all, the practice of adjusting input and output for quality changes expresses the notion that technical change is partly embodied in labour and capital, and therefore must be seen as an economic feature in itself. But since the step from measurement to explanation has hardly or not been taken, it is to be doubted whether production theory is sufficiently equipped to assess the role of technical change in the process of economic development, let alone to explain this role 2).

During the last decade, the growth accounting debate seems to have withered away somehow, or at best seems to be in a sort of status quo position. Together with the development of econometric methods - a technical change in itself - there remains a lot of fine-tuning to be done on empirical computations. Against this, it seems that the more theoretical debates of the Sixties and the Seventies are merely reviewed, not elaborated upon in the Eighties. Perhaps this somewhat regressive development is the result of both the widespread doubts that have been raised against the treatment of technical change within production theory, and the attraction other approaches have aroused.

2.4.2 Induced innovation

A common line of reasoning is based on the theory of induced innovation, which in turn relies heavily upon the works of Hicks.

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1) Cf. Lave (1966:20): "The main service of this model is that it brings everything out into the open so that each difficulty may be considered in turn."

2) Cf. Nelson and Winter (1977:46) found the production theory framework insufficient and advocated a "more fine grained theoretical structure".

His basic argument was already highlighted in point three of chapter 2.3.2. Rosenberg (1976:109) summarized the main point of criticism:

> *"Hicks's position that changes in factor prices lead to innovations involves a confusion between technological change and factor substitution. The current position, as expressed by Fellner, Salter, Samuelson, and others, is that under competitive conditions an individual firm is simply not interested in the particular factorsaving bias of technical improvements (..)(for) when each factor is being paid the value of its marginal product, then all factors are equally 'cheap' and equally 'dear' in the eyes of a competitive firm." 1)*

In fact, this passage contains in a nutshell the main elements of an extensive and lengthy discussion among economists. The first element is the "confusion between technical change and factor substitution". As we have seen in the foregoing chapter, a number of economists have tried to separate these two phenomena quantitatively. If one is predominantly concerned with the rate of technical change, a lot can be said in favour of such an approach. However, when its nature or direction is the object of analysis, it is highly questionable if this confusion can or even should be avoided. The criticism touches tautology since - logically - technical change can only be separated from (pure) factor substitution in the absence of biases. For biases by definition involve factor substitution. But whether these biases occur, and what they consist of, can only be determined by allowing for changes in factor ratios due to technical change. Binswanger (Binswanger and Ruttan, 1977:215 a.f.), while adhering to the Hicksian framework, tried to solve this problem by determining a) the degree of "ordinary" factor substitution (by measuring the elasticities of substitution in "an independent sample"), and b) the real observed magnitude of factor substitution, and subsequently c) the difference between real and ordinary factor substitution. Obviously, the accuracy with which the independency of the sample can be established is of great influence upon the results of this method 2).

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1) This discussion is also dealt with by, amongst others, Lave (1966), Mansfield (1968), Salter (1969), Kennedy and Thirlwall (1972), Heertje (1973), and Link (1987).

2) Another problem relates to the question as to how to identify 'capital' properly. For example, Nadiri remarked that labour-saving biases generally are easier to perceive in practice (Nadiri, 1970:1147). In addition the Cambridge school from the U.K. even questioned the validity of treating 'capital' as a factor of production distinct from 'labour'. See e.g. Pasinetti (1959) and Rymes (1971).

In any event, it must be concluded that the confusion mentioned actually is a rather necessary mixture, and that - however poorly defined - there are ways to deal with this confusion.

The second element concerns the decision process within firms with regard to technical change. According to the critics mentioned in the quotation, there is no micro-economic a priori justification for biased technical change as a reaction to changed price ratios. Setting aside the problem that these marginal prices must be known rather accurately, this argument can only be maintained when renouncing expectations about future price ratios as well as the possibility that firms can conduct their own research activities (which can be directed explicitly towards these expectations) 1).

Thirdly, Salter's criticism (which has been the most influential) only refers to changes in the absolute price level of a certain factor. Salter (1969:43):

> *"When labour costs rise, any advance that reduces total costs is welcome, and whether this is achieved by saving labour or capital is irrelevant."*

Although this statement indeed cannot be refuted, Salter adds in a footnote that ".. the cost of a factor has no meaning except in relation to product or other factor prices", which brings us back into the Hicksian framework again.

Thus, we must conclude that much of the criticism against the Hicksian framework seems somewhat out of place, or - at least - that the Hicksian notion stating that changes in the relative prices of factors influence the direction of technical change cannot be refuted that easily. The question of whether or not biases occur (and how these should be measured) constitutes only a part of the issue. Another is the generation and implementation of new techniques and technologies in a world with constantly shifting relative price ratios. The Hicksian framework implicitly assumes an immediate response of "technology" to "economy". The so-called evolutionary approach has shown this to be a problem in itself. We will return to this matter more explicitly in paragraph 2.4.5 and in chapter 4.

2.4.3 Patent statistics

One of these other approaches stems from Jacob Schmookler, who tried to analyze the economic determinants of technical change in a completely different manner. Instead of working with conventional economic data in an aggregate fashion, he traced down technical change by investigating historical patent statis-

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1) Cf. Rosenberg 91972), De Groof (1977), and Binswanger and Ruttan (1977).

tics. He considered patent data to be an albeit rough, but sufficiently reliable indicator of inventive activity. Assessing the numbers and timing of patents per industry 1), he tried to get an image of both the rate and the economic determinants of technical change (Schmookler, 1962 and 1966). Leaving aside some problematic features of this approach 2), Schmookler's conclusions are worthwhile.

First of all, he concluded that demand-side forces are most crucial in determining resource allocation, while supply-side forces are the most influential in determining resource exploitation. In the words of Mansfield (1968:35):

> *"..demand conditions determine which industries or consumer activities inventions are made for; supply conditions determine which industries or branches of science and technology inventions are made by."*

Secondly, Schmookler found a high degree of correlation between the level of investment and value added on the one hand and the number of patents on capital-goods invention on the other hand, the first lagging some years behind. Schmookler had a simple explanation for this phenomenon:

1. invention is an economic activity,
2. expected gains are related to expected sales of goods embodying the invention, and
3. expected sales of these improved capital goods are related to present sales of capital goods.

Schmookler's view consequently lends some support to the opinion that society can positively steer technical change and that "an interpretation of history as largely the attempt of mankind to catch up to new technologies is a distorted one" (Schmookler 1962:1). This view also corroborates the contention that the economic analysis of technical change should be directed towards more than just the process of adoption and diffusion.

The empirical basis of Schmookler's demand-pull theory, however, is rather weak. Kleinknecht and Verspagen (1988) claim that a - from the statistical point of view - more correct interpretation of his data and graphical illustrations shows a much less

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1) Schmookler used a) time-series analyses for the railroads, oil-refineries and the construction industry (the time-period involved was approximately from 1850 to 1950), and b) cross-section analysis for over 20 industries (in the 1940's). See De Groof (1977) for a short abstract.

2) See for example Mansfield (1968:34), De Groof (1977: 150-151) and Stoneman (1983:17-18), who question the validity of patents as a proper indicator of inventive activity, let alone technical change.

strong relationship between investment and patenting activity than Schmookler contended. Furthermore, by adding a scale variable to account for the possibility that the alleged high correlation between investment and patenting might be the work of a third factor, Schmookler introduced, according to Kleinknecht and Verspagen, a "clear-cut case of multicollinearity" (Ibidem: 5), since Schmookler's size variable (the number of people employed) correlates strongly with the level of investment. An upgraded application of Schmookler's theory to Dutch industry figures left the authors with the same conclusions, i.e. that there is reason "to be surprised about the wide-spread acceptance of his 'demand-pull' hypothesis" and that "even if demand and innovation prove to be significantly related, our findings do suggest that there are obviously some more factors at work, which still need to be assessed" (Ibidem: 16). With this latter remark the authors obviously argued for a less artificial treatment of technical change than the ones resulting from the demand-pull versus technology-push debates. An influential school that has tried to surpass this debate will be the subject of the next paragraph.

2.4.4 Demand-pull versus technology-push

In previous paragraphs we dealt with Schmookler's thesis on the origins of investments in new technologies, and with Schumpeter's view on the role of innovations. Somewhat contrary to Schmookler's intentions (Coombs et al, 1987:96), his work soon became one of the examples of so-called demand-pull theory. According to Dosi (1982:149) a "pure" form of this theory would consist of the following elements:

> *"(1) There exists a set of consumption and intermediate goods, at given time, on the market, satisfying different 'needs' by the purchasers. (..)*
> *(2) Consumers (or users) express their preferences about the features of the goods they desire (..) through their pattern of demand. (..)*
> *(3) .. with a growing income relaxing the budget constraint of the consumers/users, the latter demand proportionally more of the goods which embodied some relatively preferred characteristic. (..)*
> *(4) At this point the producers enter into the picture, realizing - through the movements in demand and prices - the revealed needs of the consumers/users: some 'utility dimensions' have a higher weight (there is more need for them). (..)*
> *(5) Here the proper innovative process begins, and the successful firm will at the end bring to the market their new/improved goods, letting again the 'market' (..) monitor their increased capability to fulfill consumers' needs."*

The counterpart of demand-pull theories cannot be fitted that easily into an idealized image. The central argument is that technical change is an essentially autonomous factor with regard to economic processes. Under the umbrella of this argument we can find a very heterogeneous group of views: on the one hand pure neoclassical theorists (with their shift-thesis as mean feat) and pure Schumpetarians on the other hand (with their emphasis on the primacy of innovative activities in the evolution of business cycles; see 2.3.1).

Obviously, a logical way-out of this controversy is to relax both contentions and to develop some sort of a synthesis. One of the most promising - and relatively recent - attempts to construct such a more inclusive theory can be captured under the heading of evolutionary approach , with which we will deal quite extensively in the following section.

2.4.5 Evolutionary approach

Essentially, the evolutionary approach looks upon technical change more or less from the micro- and meso-economic point of view. It is before all concerned with the strategies and decision-making process within firms and firm conglomerates vis-à-vis both adopting and generating new techniques and methods of production. Furthermore, the evolutionary approach is often presented as a critical alternative for standard neoclassical microeconomic foundations. Firstly because the behavioral postulate of utility maximizing is relaxed by means of the principle of "satisficing" 1). Secondly, in contrast with neoclassical analysis, non-equilibrium, discontinuity and asymmetry constitute the modus operandi within evolutionary thinking 2).

The most interesting feature of this approach undoubtedly is the avowal that economic processes are far more complex than suggested by neoclassical theory. Especially in the case of technical change, any analysis seems to be hampered from the beginning when no account is taken of the fact that dynamic processes are almost inherently uneven and unstable of nature, rather than even and stable (or "tending towards equilibrium").

Since Nelson and Winter (1977) and Dosi (1982;1984;1988) can be considered as the most prominent spokesmen of the evolutionary approach, we will call their collective ideas, following Van den

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1) Winter: "At some level of analysis, all goal seeking behavior is satisficing behavior. There must be some limits to the range of possibilities explored, and those limits must be arbitrary in the sense that the decision maker cannot know that they are optimal." (Cited in Elster (1983:140).

2) Because of the second feature, representatives of the evolutionary approach are also referred to as neo-schumpetarians (cf. Boyer, 1988).

Belt and Rip (1984), the Nelson-Winter/Dosi model. This NWD model is centered around a number of key concepts which we will present first, in order to discuss them afterwards.

2.4.5.1 Paradigms, trajectories and paths

The first concept is "technological paradigm" 1), which is more or less analogous to Kuhn's scientific paradigm. Dosi (1988:1127):

> *".. as modern philosophy of science suggests the existence of scientific paradigms (or scientific research programs), so there are technological paradigms. Both scientific and technological paradigms embody an outlook, a definition of the relevant problems, a pattern of enquiry. A 'technological paradigm' defines contextually the needs that are meant to be fulfilled, the scientific principles utilized for the task, the material technology to be used. In other words, a technological paradigm can be defined as a 'pattern' of solution of selected techno-economic problems based on highly selected principles derived from the natural sciences, jointly with specific rules aimed to acquire new knowledge and safeguard it, whenever possible, against the rapid diffusion to the competitors. (..) A technological paradigm is both an exemplar - an artifact that is to be developed and improved (such as a car, an integrated circuit, a lathe, each with its particular techno-economic characteristics) - as a set of heuristics (e.g., Where do we go from here? Where should we search? What sort of knowledge should we draw on?)."*
> (accentuations original, HR)

The second concept is "technological trajectory" and refers to the more or less everyday's form in which technological paradigms manifest themselves. Dosi (1982:152):

> *"We will define a technological trajectory as the pattern of 'normal' problem solving activity (i.e. of 'progress') on the ground of a technological paradigm."*
> (accentuation original, HR)

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1) Dosi uses an 'impressionistic' and very broad definition of technology, running as follows: ".. a set of pieces of knowledge, both directly 'practical' (..) and 'theoretical' (..), know-how, methods, procedures, experience of successes and failures and also, of course, physical devices and equipment." (Ibidem: 14).

These "normal" problem solving activities can still be directed towards various applications, the variety of which is called technological paths (Dosi, 1982:153).

2.4.5.2 Fundamental characteristics

Thus, the conceptual structure runs from the global to the specific: paradigms set the boundaries for trajectories, and paths can be followed along trajectories. Now each segment of this layered structure of concepts exists by the grace of a number of inherent characteristics:

1. They are shaped through a process of selection from a broad collectivity of facts and variables that a) determine the extent to which advances within a paradigm, trajectory or path can be achieved, and b) function as selective devices with regard to the direction this progress (or retrogression) can take 1). The specificity of the way in which selection takes place will often be greater for paths than for paradigms, if only because of the fact that these paths will be more concrete. Generally speaking the process of selection will involve one or more of the following elements:
   - the science and technology base, i.e., the state of knowledge, respectively the state of the art, as partly reflected by the "cultural matrix" of scientists and engineers, reflecting on its turn the expectations and accepted beliefs with respect to the directions of their search activities (Van den Belt and Rip, 1984:32 a.f.);
   - the economic base, or the "market", consisting of factor price ratios, factor intensity ratios, the competitive structure of firms and sectors, income distribution, consumers demands, etc.;
   - the institutional base, i.e., the juridical and/or actual expression of relations of property and authority).

   These environmental elements ultimately determine the rate of technical change, they determine through which trajectory

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1) Although Dosi speaks of the *selective* environment, others (e.g., Nelson and Winter (!) (1977), Coombs et al, 1987) have used the term *selection* environment to describe the same aspect. This is much more than a matter of semantics: to Dosi the act of selecting by the environment is apparently more meaningful than the act of selecting out of the environment. Thus, the circumstances under which technology producers take their decisions represents - according to Dosi - a set of constraints, rather than a set of opportunities. Roobeek also mentions this problems and suggests to use the term 'environmental pressure' in stead of selective environment. (Roobeek, 1988:39).

or trajectories this advance is to proceed, and they form the criteria upon which new technological paradigms may or may not be selected (Dosi et al, 1988:228).

2. Another characteristic is the other side of the coin of the first, namely the exclusion effect: whenever decisions are being taken in order to address whatever problems, this implies deciding upon alternatives and even upon the problems to be (or not to be) addressed:

   ".. the efforts and the technological imagination of engineers and of the organizations they are in are focussed in rather precise directions while they are, so to speak, 'blind' with respect to other technological possibilities."
   (Dosi, 1982:153)

   The exclusion effect of paradigms is evidently stronger (more "powerful") than that of trajectories or paths, but there is no reason why this phenomenon should be restricted to the first.

3. A final characteristic common to the three concepts is the cumulative content of progress, i.e., the embroidering on what already exists in terms of knowledge, research methods and techno-economic possibilities. Dosi even presents this as a "stylized fact on innovation":

   ".. it seems that the patterns of technological change cannot be described as simple and flexible reactions to changes in market conditions: (1) in spite of significant variations with regard to specific innovations, it seems that the directions of technical change are often defined by the state-of-the-art of the technologies already in use; (2) quite often, it is the nature of technologies themselves that determines the range within which products and processes can adjust to changing economic conditions; and (3) it is generally the case that the probability of making technological advances in firms, organisations and often countries, is among other things, a function of the technological levels already achieved by them."
   (Dosi et al, 1988:223) 1)

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1) Cf. Nadiri (1970:1149): ".. the most important impediment to diffusion of the new techniques is the existence of old capital stock and product".

2.4.5.3 Economy and technology

Within this family of rather tentative and even multi-interpretable concepts and characteristics, one quickly loses sight of the wood for the trees. The matter becomes somewhat clearer once the operation of the selective environment is dealt with more extensively. Especially Dosi's distinction between ex-ante and ex-post "criteria of selection" seems quite helpful in this respect. For although some very broad criteria such as feasibility, marketability and profitability are assumed to operate as selective devices at almost each level within the process of technical change, Dosi rightly comments "on these very general grounds, there might still be many possible technological paradigms that could be chosen" (1984:18) and moreover claims that "especially at the initial stage of the history of an industry" the ex-ante selective force of market mechanisms is weak (Ibidem:19). Once a technological pattern has become an established feature, market mechanisms become more powerful in the sense that they act as "a system of rewards and penalties, thus checking and selecting upon different alternatives" (Ibidem:20). But the crux of the argument is that these alternatives come forth from prevailing trajectories rather than embodying new or potential trajectories.

For example, when confronted with the question as to why there are such great differences in innovative activities among enterprises and economic sectors, Dosi argues that this is to be accounted for by the interplay between, on the one hand, differences in technical and scientific opportunities, and in the degree of appropriability (of the gains of an innovation), and "various sorts of market inducements" on the other hand (Dosi, 1988:1140-1141). The influence of these market inducements (like changes in demand and in relative prices) is exerted "primarily by stimulating, hindering, and focusing the search for new technological paradigms". However, once a new paradigm is established, it "remains quite 'sticky' in its basic technical imperatives, rules of search, and input combinations" (Ibidem: 1142).

Thus, crudely stated, Dosi's opinion seems to suggest that the creation of (new) technological paradigms is a predominantly exogenous (i.e., non-economic) process, whereas the emergence of (new) technological trajectories is heavily determined by economic factors. However, this image should be adapted at two points. The first can be illustrated by a fragment from Dosi (Dosi et al, 1988:292) himself:

> *"Economic dynamics is capable of shaping the patterns of 'normal' technical change along defined technological trajectories, within boundaries defined by the latter. On the other hand, the emergence of radically new technological paradigms cannot be simply explained by economic drives: more correctly, it stems from the complex interplay (..) between advances in science, institutional factors and economic mechanisms."*

Secondly, evolutionary theory has taken under its wings some "regulation" theorists, according to whom technology plays a crucial role in maintaining or changing the politicoeconomic hierarchy of a society. Technology, so to speak, is considered to be a tool in the act of regulating this hierarchy 1). Roobeek (1988) has recently elaborated this line of thinking in her study of government policies with regard to technology from the perspective of the international structuring of political hegemony and economic competitiveness.

Yet, as Van den Belt and Rip (1984:43-44) rightly argued, Dosi's general contention that economic factors operate as "selective criteria, as final ('market') checking and as a continuous form of incentives, constraints and 'feed-back' stimuli" (Dosi, 1982:159) still leaves us with the question of how and when "economy" intervenes in "technology".

2.4.5.4 Technology systems

Roobeek has added to the family of concepts mentioned before the concept of technology webs, referring to the observation that most of the significant, influential technologies often are or become surrounded by "a web of innovations and new applications in very different fields" (Roobeek, 1987: 141; my translation, HR). Obviously, this concept includes the complexity of relations and developments that goes along with the introduction and diffusion of new (key) technologies. An example of such a web - a "biotechnology web" - is presented in chapter 4. More in general terms webs are an excellent expression for the systematic features of the direction and rate of technical change: the coming into being of new or at least significantly different technical patterns is not an isolated phenomenon, but involves some sort of "orchestration" by many actors (scientists, engineers, entrepreneurs, consumers, institutional bodies, etc.) as a result of which more or less closely-knit systems may arise. In fact, one of Dosi's "stylized facts" of innovation is that there is an historical tendency of "an increasing complexity of research and innovative activities (which) militates in favour of more formal organisations (..) as opposed to individual innovators as the most conducive environment to the production of innovation" (Dosiet al, 1988:223).

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1) "Certainly in societies where industrial conflict and conflict over income distribution are structural features, substitution of machines for labour must be a powerful determinant in the search process for new technologies." (Dosi, 1984:19) See also Boyer (1988).

2.4.5.5 An example: agriculture

The evolutionary approach has been applied to agriculture by Sahal (1979 and 1981) in his search for the determinants of technological innovation. With the farm tractor as case-study (for US agriculture during the period 1920-1968), he tested two hypotheses:

1. "..technological innovation originates in the accumulated experience of a practical nature" ('learning by doing'); and
2. "..the process of innovation is (further) governed by a change in the scale of the larger system in the use of the technology" ('specialization via scale'). (Sahal, 1981:399).

Although anticipating the following chapters, one finding of interest is that Sahal assessed that technological innovations with regard to this type of mechanization were determined by the existing size structure of agriculture, rather than the other way around. That is to say, innovations in farm tractors remained within the framework of the family farm 1).

Within this paradigm, however, technological innovation has a technological momentum of its own. That is to say, although socio-economic variables exert an apparent influence, he calls for more attention to 'internal, system-specific' variables of which the influence more or less depends on the type of technology, and the type of productive system concerned (Ibidem:399). Thus, he criticizes Schmookler's demand-pull theory for not accounting for the fact that although there may exist a tangible demand for a certain technology, this does not guarantee the production of such a technology. (Whereas, on the other hand, the possibility that technologies are being produced for which there is as yet no demand should not be discarded (Sahal, 1979:35-37)) Likewise, Sahal found no direct confirmation of the Hicksian induced innovation theory (see 2.4.2), only indirect through the above mentioned size-variable (which is induced by labour costs). He therefore thought this theory to apply only to long-term developments.

2.4.5.6 Some final remarks on evolutionary theory

So much for the general contours of the evolutionary approach. Although the advantages of this set of theses over several others is apparent - e.g., because of the way it arranges technological, economical and institutional influences - its validity and usefulness with respect to a general understanding of the process of technical change remains to be sorted out. In

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1) ".. while advances in technology were largely governed by certain technical characteristics of the farm organization, the farmer in turn had little influence on the latter". (Sahal, 1981:373).

each publication, Dosi himself warns the reader not to interpret his views too mechanically, and to apply them with due caution.

We finally have to pose one more question with regard to the NWD-model, namely: which are the most essential reasons for the mere existence of paradigms and trajectories? In other words, why should technical change indeed not be a black box of at random phenomena? Evolutionary theory would explain the existence of a technological paradigm by first pointing at the channelling influence of normal problem solving activities by the main actors: scientists, engineers and producers; an influence that a) consists of mainstream knowledge, or a knowledge base most actors agree upon (cf. the moving positions of hegemony within economic theory!), b) is maintained by their cultural matrix (of penalties on deviations and rewards for advances along the paths agreed upon), c) is shaped and reshaped by the continuous evolution of a politico-economic and institutional environment of which the actors themselves are increasingly important members.

2.5 Diffusion of new techniques and technologies

The rate of diffusion of new techniques obviously is one of the main determinants of the rate of technical change. After a certain innovation has been introduced, its economic impact is governed largely by the speed and manner of its commercialization. Generally speaking, three situations may occur after the introduction of an innovation:

1) It fails at the very beginning of its entrance;
2) It passes through the complete process of diffusion in its original shape;
3) It passes through the diffusion process while (constantly) being reshaped 1).

Furthermore, there exists a more or less considerable time lag between the availability and the application of new techniques. Similarly, these new techniques rarely are evenly spread across regions, economic sectors, and types of firms.

The explanation of these kinds of lags, and consequently of the diffusion process itself, is usually conducted in terms of determinants which are thought to exert influence on the (rate of) adoption of new techniques. Metcalf (1970), for example, listed three groups of determinants:

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1) Rosenberg (1976:75) stated that it is too often forgotten that diffusion inevitably involves "continued technological and engineering alterations and adaptions, the cumulative effects of which decisively influence the volume and the timing of the product's sale".

1. Economic factors, which determine the extent to which new techniques reduce costs of production, and/or increase profitability;
2. Technical factors, that is, whether these new techniques offer a solution to technical bottlenecks within the production process, and whether they fit into the present situation;
3. Socio-cultural factors, that is, whether and how these techniques tally with existing norms and values.

Each of these factors may be subdivided further, by paying closer attention to the specific conditions under which they are relevant. Thus, the economic determinants may subsequently depend upon a) the size of the production units, b) the financial risks involved, c) the pay-off period, d) the costs of switching from old to new techniques, and so on.

Of course, this list presumes an instant 100% availability of new techniques, a condition that seldom holds and that ignores the fact that a great number of inventions never reach the commercial stage and that many innovations turn out to be failures. In addition, as suggested above, the diffusion process is determined to a great extent by the possibilities of improving or adjusting the original innovation. A technique which can be enhanced and modified easily so as to fit specific circumstances will probably show a completely different pattern of diffusion than the technique for which this is not possible at all. The agricultural economists Hayami and Ruttan (1985;chapter 9), for example, emphasized this aspect in their dealings with the international transfer of agricultural technologies; for costreducing technologies to become widely adopted, they not only need to be appropriate for the specific agronomical conditions, but their availability also needs to be assured and their introduction attended, thus becoming institutionalized.

The pattern of diffusion is mostly described by means of the well-known S-shaped curve 1):

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1) Norris and Vaizey (1973:72 a.f.) present some examples of actually observed S-shaped curves. One peculiar phenomenon of this curve must be noted: unless the innovation is diffused in a very short span of time, the category depicted on the vertical line is likely to change during the process of innovation. This may not only occur as a result of, e.g., demographic factors, but may also be the result of the innovation itself. For example, an innovation can place early adopters - for whatever reason - in such a superior competitive position, that potential 'followers' are wiped out of business. See e.g. Cochrane (1958).

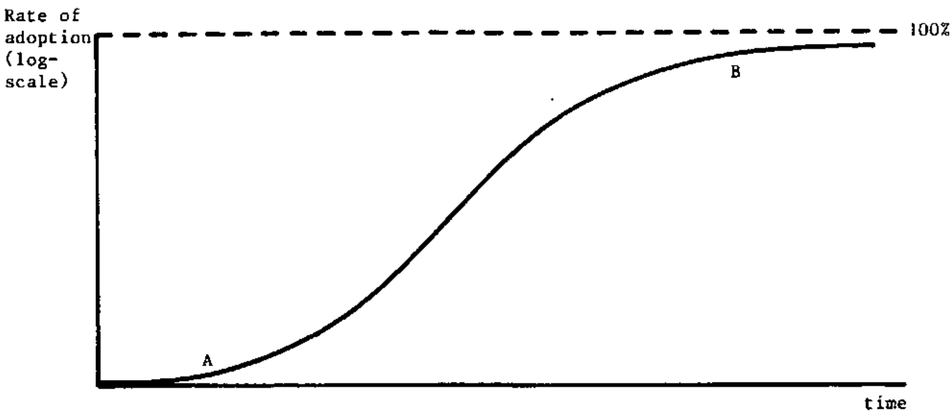

Figure 2.4 Diffusion of innovation

During period A, only a minority adopts the new technique and consequently receives the title "innovators", while adopters who come after the majority, are negatively dubbed "laggards". In between are the so-called "early" and "late" adopters. These descriptions are of a rather psychological nature, since they tend to focus on the (mental) characteristics of possible adopters. But both the nature of the technique to be diffused and the technical-economic characteristics of the firm must influence the shape of the curve as well. For it is here that the possibilities for imitation and adaptation, the scale-sensitivity, as well as the problem-solving character of the innovation come into the picture. And perhaps one of the most decisive factors with respect to the possibilities to adapt innovations to local, micro circumstances is whether the risks involved can be reduced. Logically, this applies primarily (but not exclusively) to the range of the "early birds" (Norris and Vaizey, 1973:99). Mansfield (1968:123), for example, hypothesized that the question of who becomes the innovator and who the laggard, depends among other things on (a) the size of the firm, (b) the growth rate of the firm, (c) the profit level of the firm (d) the age structure of the firm's management, and (e) the liquidity of the firm. (However, a test on the influence of these determinants, showed only the size variable to be of significant influence.)

A general determinant of the diffusion process itself is *learning* 1), that is to say, it involves drawing conclusions from experiments, and the application of general knowledge to specific (new) problems. In addition, it seems that especially after World

1) Mansfield (1968:112): "The diffusion process (..) is essentially a learning process".

War II, this element has by an equally influential one, namely communication. For with the multiplication of new ways to rationalize the production process, it becomes the more important to get to know as much as possible about these new ways, the more so when the risks involved do not change or - as can be expected - even become greater over time (Brown, 1981).

2.6 Conclusions

General economic theory has only recently settled accounts with the habit of treating technical change as an agent outside the economic sphere, thereby revaluing the merits of "classical" economists. In that sense we could speak of a theoretical wave with regard to the treatment of technical change by economists. However, because of the many conceptual problems and confusions which remain attached to treating technical change as an economic factor, there still is a long way to go before we can definitely discard its magic character. Rather than the growth-accounting approaches, induced innovation theory and the demand-pull versus technology-push debates, the more recent attempts to endogenize the process of invention and innovation seem more promising. This applies especially to the consideration of technical change as being an economic factor in itself, acknowledging that:

a) technical change is not merely a matter of choosing from a number of (new) blueprints, for it will involve new investments, and new structures of input and output;
b) the coming into being of new techniques is an economic process in the sense that it inevitably involves economic decisions;
c) technical change is all but "falling from heaven" and instead an inherent element of industrial structures and dynamics, and therefore "man-made";
d) finally, technical change often is of such decisive importance to the economic performance of firms, sectors and national economies, that it would be hard to imagine a world in which economic actors do not have strategies regarding the use and production of new techniques and technologies.

Although these acknowledgements have by now indeed become common knowledge among economists, it also turned out that economic theory provides no explanation for the more crucial elements of the process of technical change. The evolutionary approach in particular has made clear that although (1) technical change is indeed heavily determined and shaped by economic variables, and (2) technical change itself also affects these economic variables, its understanding requires specific theoretical concepts, as well as the acknowledgment that technical change is governed by more than economic variables alone. Thus, one conclusion from this chapter must be that only when integrating scientific, institutional and political dimensions with economic analyses, there is a chance to penetrate the black box of technology.

In the following chapters we will find out whether agricultural economists have performed any better than their colleagues in the field of general economy in this respect.

3. Technical change and agricultural economic theory

"Should we be able to increase substantially our knowledge of conditions surrounding decisions on various types of innovations (..), we could usefully and more readily project from discovery of a new innovation to future output quantities."
(Heady, 1958)

We consider technical change in agriculture to be a special case within general economic theory. Thus, our proposition is that the findings of economic theory cannot be easily applied to agriculture. The main reason for this is the existence of some major differences between agriculture and most other sectors within Western economies. Thus,

a) agriculture is made up of relatively small production units (small in particular in terms of the number of people employed per firm);
b) a relatively high degree of public and (non-farm) private sector intervention has been established in agriculture over the past decades.

Furthermore, a lot can be said in favour of the argument that agriculture is distinct from other sectors, simply because of its dependency upon land, this relatively peculiar factor of production 1), and because of the fact that it supplies one of the most primary of goods, which is food.

In this chapter, emphasis lies upon the views of agricultural economists and cognate disciplines on the determinants and - to a lesser extent - diffusion of technical change in agriculture. Prior to this, a brief survey of the many forms in which technical change may appear in agriculture is given 2).

3.1 The many shapes of technical change in agriculture

In many respects, agriculture in developed countries has been transformed by technical change in ways akin to those in other sectors. Contrary to the classical thoughts of for example Smith, Ricardo and Marx, agriculture proved to be quite susceptible to new sources of productive dynamics. According to Lave (1966) technical change in U.S. agriculture from 1910 to 1950 has

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1) Peculair, because of its literally immobile and non-reproducible character.
2) A short but very useful review may be found in Peterson and Hayami (1977).

been twice as rapid as in the non-farm sector, a statement which is illustrated by figure 3.1 1).

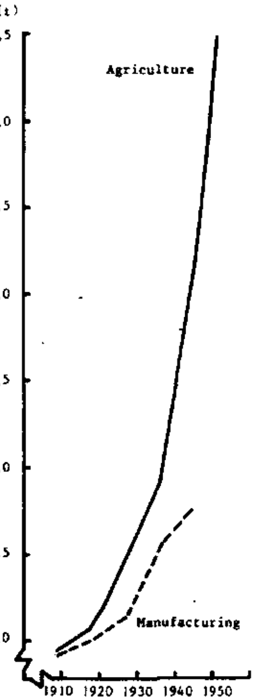

Figure 3.1 Technological change in agriculture versus manufacturing
Source: Lave (1966:66)

In the preceding chapter, however, we have seen that measurements of technical change often should be taken with a grain of salt. Still, we may safely say that, as far as technical change is concerned, agriculture certainly proves to be a match for other sectors. In the following we will merely touch upon the question as to why the classicals were "wrong" on this point. Of primary interest will be the explanations for both the rate as well as the direction of technical change in agriculture. For that purpose we have to deal with the manifold appearances of technical change in (primary) agriculture.

In general, we can distinguish two forms of technical change:

---

1) According to the following definition: $dT = dY/Y - Wk.dK/K$; K standing for capital, Y for income and wK for the share of capital in income.

- those connected with the production process (process innovations), and
- those which concern the final product (product innovations).

Again, this distinction is far from waterproof. For example, we can think of a new product, like a new wheat variety, which is a prerequisite for a process innovation, for example a new method of harvesting. To avoid such misunderstanding, we will define process innovations as all those innovations that have a visible effect upon the production process and not necessarily upon their final product. This definition is, obviously, formulated from the point of view of primary agriculture. Thus, a new wheat variety is considered as a process innovation (to primary agricuture), although at the same time it leaves the gate of a research institute or a seed company as a product innovation.

A final point to be made, more or less related to this matter, concerns the particular form of agricultural technology as compared with industrial technology. It seems that agricultural technologies have moulded themselves remarkably well upon the family-based structure of production, whereas technologies in industrial sectors are generally not restricted by such small scales of production, that is, when scale is expressed in terms of labour requirements. Clark (1985:94) remarked with respect to scale economies in industries:

> *"Economies of scale are sometimes classified into two types (a) technical and (b) pecuniary. The former relate to technical and organisational conditions of production, for example the lower costs associated with spreading overhead resources such as power, insurance and management time or the greater flexibility in deploying resources in a multi-product firm where there is a greater possibility of 'hedging' against market uncertainty, thereby lowering average costs for the firm as a whole. Another well-known example is the capacity to afford R&D expenditures at the level necessary to stay abreast of relevant innovative developments and thereby to lower the costs in the future. Pecuniary economies of scale concern the greater market power that larger firms sometimes possess - for example, to force suppliers to cut the prices of their products under threat of withdrawing custom altogether."*

Obviously, the role of economies of scale in primary agriculture is not only restricted to Clark's first type, but also of yet another dimension. By the latter we mean that the examples Clark mentions do not apply to agriculture as universally as they do to industries: farm-firms are usually less of a "multi-product" character, their "flexibility in deplying resources" and their possibilities to "spread overhead resources" are relatively small, etc. Nonetheless, in agriculture as well, technical change and economies of scale must be strongly related to one another.

In chapter two we already referred to Sahal's empirical findings that mechanical innovations in US agriculture during the first half of the 20th century were more determinded by (changes in) the existing scale of production at the firm-level, rather than the other way around. This need not be the case in general, for innovations may also create or increase economies of scale. We will return to this subject in chapter five.

3.1.1 Process innovations

According to Hill and Ingersent (1977:59-60), process innovations share three common features; they:

1. decrease costs per unit of production,
2. increase revenues per unit of production, and
3. increase total output (at least in the short run).

But when subdividing process innovation into different categories, this list has to be revised somewhat. The two major forms of process innovations in agriculture are mechanical and biological (or bio-chemical) innovations. Hill and Ingersent define mechanical innovation as

> *"improvements to the design and performance of existing types of farm machinery, as well as with the design of new types",*

biological innovations as,

> *"breeding and selection of higher yielding and higher quality crop varieties and strains of livestock",*

and chemical innovations as,

> *"improvements in fertilizer technology and more efficient methods of controlling pests and diseases by chemical methods".*
> (Ibidem:59)

Since the two latter types of innovation apply directly to the physical performance of plants and animals, they are often taken together. A third form can be added, namely innovations in the organizational spheres, that is to say in the field of farm management. We will label them organizational innovations 1). A possible definition could be:

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1) See Steffen (1974/75), and Binswanger and Ruttan (1978:370). With the automation boom of recent years, this type of innovations has obviously become of greater importance.

"improvements in the organization of the farm activities, ranging from insights in and knowledge of husbandry practices to the flow of information vis-à-vis all agriculture oriented firms and institutions".

Self-evident as this classification may seem at first sight, two major difficulties arise immediately. First, we can think of innovations which - after being identified as such, which often is a problem in itself - cannot be placed that easily in either category. For example, new methods or techniques of land reclamation and re-allotment; should these be considered as mechanical or as organizational innovations, as both or as neither of the two?

Secondly, as was already mentioned, we can deduct that many innovations do not stem from agriculture itself, but in fact are "produced" elsewhere. Take fertilizers for example: should these be considered as a product innovation to agriculture, and as a process innovation to the chemical industry, or the other way around? Here we should give priority to what came first: the new ways to produce fertilizer (much cheaper), thus to the innovative process 1). To agriculture it thus appeared as a product innovation (even though it may have led to new methods of farming!). Strictly speaking, therefore, we should always clarify the position from which this distinction is being made: the individual firm (micro), the sector (meso), or the (inter-)national economy (macro).

In fact, this second problematic feature pinpoints an important historical development farming has gone through; Bolhuis and Van der Ploeg (1985), for example, argued that the capacity of primary agriculture to develop innovations autonomously, has decreased significantly in the course of time. And:

"Agrarian growth becomes to an increasing extent a function of production and adoption of externally developed innovations".
(Ibidem:404;my translation,HR).

In other words, they suggest that innovations of agriculture have become more and more innovations to agriculture, or in other words that agriculture has become an innovation-using rather than a innovation-producing sector. Similarly, Kislev and Peterson (1981) criticized theories on "induced innovation" for their neglect of problems involved in the intersectoral transfers of technology, problems which would make it necessary to

"..separate the sector where the technology is developed from the sector where it is used."
(Ibidem:562)

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1) See Kislev and Peterson (1981:562).

Obviously, when investigating the sources and/or production of innovations, one is bound to specify these two fields of development and application.

Notwithstanding these difficulties, a certain classification undoubtedly makes sense in economic analysis. For many economists and the like stress the fundamentally different economic impact of the above formulated types of innovation - although usually emphasis is given primarily to mechanical versus biological-chemical innovation. Why is this distinction so important to many agricultural economists? We will review some arguments.

In his work on "The agrarian question in Latin America", De Janvry (1981) listed the following differences between mechanical and biological-chemical technology in agriculture:

Mechanical technology	Biological-chemical technology
-labor-saving	-land-saving (yield increasing)
-promotes economies of scale	-increases labor and management needs
-reduces management needs	
-reduces labor costs for the producer and (indirectly) for the economy as a whole	-increases labor costs throughout the economy
-protects the land monopoly of the landed elite	*-no monopolization of surplus possible (extraction through market prices)*
-increases differential rents	-introduces contradiction between (rationality of) land owners as individuals and as a class
-enables a hierarchization of the labor process	

Source: De Janvry (1981:170 a.f.); the features in italics apply primarily, though not exclusively, to underdeveloped economies

Figure 3.2 Effects of mechanical and biological-chemical technologies

Furthermore, according to De Janvry, there is a difference between these two types with regards to the ease at which economic gains from these innovations can be absorbed by the innovators:

> *"The returns from research on mechanical techniques can, in great part, be captured by the innovating firm. This is less commonly so in the case of biological innovations since, after the first sale, the new seeds and breeds can be reproduced and disseminated by farmers themselves."*
> (De Janvry, 1978:307)

Much earlier, Heady (1949) had stressed the importance of the distinction between biological and mechanical innovation, by pointing at the immediate effects of both types on the level of output and total costs. Although he stated that "all innovations lower the per unit costs of production", when total costs are concerned biological innovations tend to increase them, while mechanical innovations tend to have the opposite effect. Furthermore, biological innovations have the propensity to increase output, whereas mechanical innovations are somewhat indifferent to volume effects (ibidem: 296-297) 1). It must be noted, however, that Heady made no allowance for the effect of each type of innovation upon variable vis-à-vis fixed costs, whereas other economists, in particular G.L. Johnson (1960), practically centered their analysis around this distinction in cost categories.

A further argument in favour of our distinction stems from a somewhat different base, that is, from a comparison between agriculture and industry. Adam Smith already struggled with this matter as we have seen. Some authors after World War Two have argued that both the socio-economic structures as well as the particular biological/physical features of agricultural production do not allow for a simple copying of machinery use in industry by agriculture. Brewster (1950) pointed out a number of "prominent cultural differences" between agriculture and industry, all influenced by technical change. Thus, he argued that "relationships of the worker to the product on the one hand, and to operations on the other", are different in agriculture, as far as the machine process is concerned: farm workers would be in control of the machine process, whereas industrial workers are tied and subordinated to it. The machine process in agriculture furthermore does not alter "the product of farming as the expression of the farmer's planning and effort", whereas in industry it "(1) institutes the hum-drum of a repititious task and (2) further tends to inflict the pains of status degradation through reducing the worker from a self-directed to a mechanical agent in his labor activity".

Obviously, a lot can be said against these somewhat romantic statements, but nevertheless Brewster's "cultural differences" indicate that the use of machinery in agriculture meets certain conditions and barriers which are unknown, or are at least less stringent, in many industrial processes. In addition, improvements in the biological spheres seem to be a "privilege" of agriculture, that is, we can think of few other sectors where manipu-

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1) Heady carries on by calling those innovations which appear to increase output and lower total costs 'biological- chemical', that is to say, innovations which increase the "time-liness of operations, (improve;HR) soil structure or otherwise directly affect the plant or animal". (Heady, 1949:297).

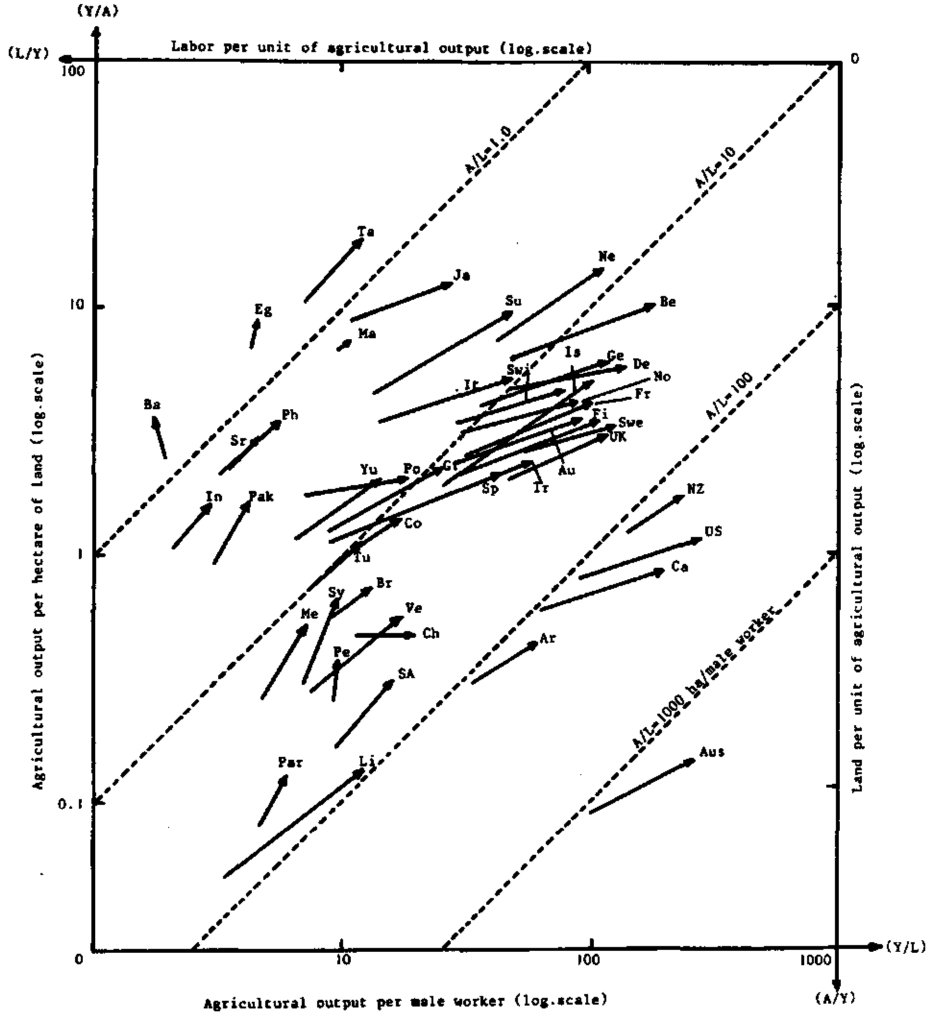
lation with plants and animals is of such weight to the economic performance of the sector.

Finally, the most frequently referred to motive behind the distinction between mechanical and biological(-chemical) innovations lies in their effect upon resource allocation. Particularly Hayami and Ruttan (1985) persuasively demonstrated that - in general - the relative scarcity of a production factor leads to implementing those kinds of technologies which are designed to, or at least suitable for saving the use of this particular scarce factor (be it in relative or in absolute terms). Consequently, labour-saving technology is predominantly mechanical, whereas bio-chemical technology comes into the picture when land is the scarce factor. As we will elaborate the "Hayami-Ruttan-" approach later on, we can here confine ourselves to their observation that:

> *".. an important aspect of this adoption (of agricultural technologies;HR) was the ability to generate a continuous sequence of induced innovations in agricultural technology biased towards saving the limiting factors. In Japan these innovations were primarily biological and chemical (..). In the United States they were primarily mechanical."*
> (Ibidem, 1970:1115)

From the studies of Hayami and Ruttan we may conclude that it is indeed warranted to distinguish the rate of technical change from its direction: whereas the agricultural sector of different countries can yield equal productivity increases, their "paths" can be totally diverging. However, as Hayami and Ruttan also show, there is a distinct tendency of convergence over time: whatever its causes, the developmental path of agricultural sectors look more and more alike, when both direction as well as rate of technical change are concerned. As far as the convergence of the direction of technical change is concerned, figure 3.3 indicates this to be the case for practically all European countries. In this figure the A/L lines represent growth paths in which a rise in labour productivity is solely caused by rising land productivity; Taiwan for example follows such a path. For arrows of which the slope is less steep than these A/L lines it holds that the rise in labour productivity is caused by an increased land productivity, combined with an increased A/L ratio.

Concluding, we can state that the actual form process innovations can take, may have its specific impacts upon the structure of input and output of farm-firms, and consequently upon their economic performance. When assuming that to decrease the cost per unit of production is the ultimate motive behind the application of new techniques and methods of production in agriculture, there are in principle three "strategies" that can be followed, as can be illustrated by means of figure 3.4.



Key:

Argentina	Ar	Finland	Fi	Mexico	Me	Sri Lanka	Sr
Australia	Aus	France	Fr	Netherlands	Ne	Surinam	Su
Austria	Au	Germany, F.R.	Ge	New Zealand	NZ	Sweden	Swe
Bangladesh	Ba	Greece	Gr	Norway	No	Switzerland	Swi
Belgium	Be	India	In	Pakistan	Pak	Syria	Sy
(& Luxembourg)		Ireland	Ir	Paraguay	Par	Taiwan	Ta
Brazil	Br	Israel	Is	Peru	Pe	Turkey	Tu
Canada	Ca	Italy	It	Philippines	Ph	United Kingdom	UK
Chile	Ch	Japan	Ja	Portugal	Po	United States	USA
Colombia	Co	Libya	Li	South Africa	SA	Venezuela	Ve
Denmark	De	Mauritius	Ma	Spain	Sp	Yugoslavia	Yu
Egypt	Eg						

Figure 3.3 Comparison of land and labour productivities for 44 countries, from 1960 to 1980

Source: Hayami and Ruttan (1985:121)

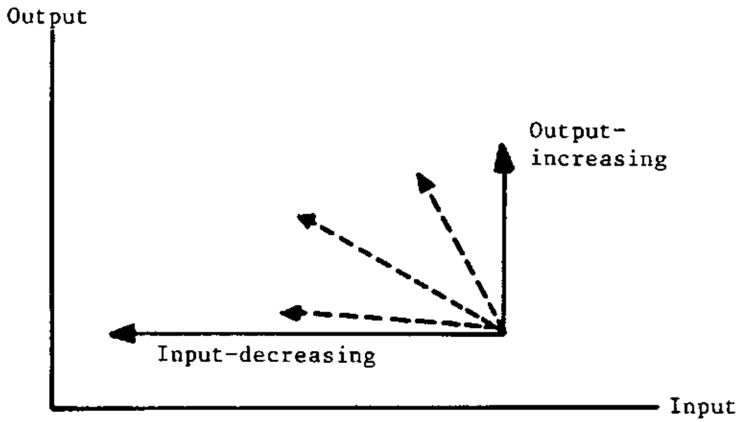


Figure 3.4 A schematic presentation of strategies involving technical change

A logical question following from this scheme is which strategies have dominated in agriculture, and why this was so. Subsequently, the role of prices in the "choice" of strategies to follow comes out into the open. In paragraph 3.3 and chapter 5, we will deal with this matter more extensively.

3.1.2 Product innovations

In order to avoid misunderstandings, we will in the following reserve the term product innovations for new agriculture oriented final products, e.g., glues from starch potatoes, a new brand of cheese, etc. Although these product innovations might well outnumber the quantity of process innovations in agriculture, we will concentrate on the latter form of technical change 1). This is done simply because of the assumption that productivity increases - as a result of process innovations - have superseded demand enlargements - as a result of product innovations - in their effect upon the economic performance of agriculture. This does not imply that product innovations do not have a substantial influence on productive performances in agriculture. On the contrary, these new products serve as an extension of the market in that they create new groups of consumers and - thus - counteract the adverse effects of the relatively low income elasticity for many food products. But the effects upon agriculture are rather indirect and less visible than is the case with process innovations.

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1) It should be borne in mind that insofar as product innovations represent a new technique to farmers, they are more or less lumped together with process innovations. See the definition of process innovation given earlier.

There is, however, one particularly interesting aspect of such a distinction between process and product innovations. For not only has primary agriculture in the course of time lost most of its (already meagre) abilities to bring forth process innovations itself, but this also accounts for innovations in the field of the final product; primary agriculture has remained or even has become to a greater extent a raw materials producing sector, although this raw material production is made with increasingly sophisticated techniques and methods of production 1).

3.2 The dual orientation of agricultural economists

Before elaborating the agricultural economic analyses of technical change, we first have to consider the motives with which agricultural economists study the problem of technical change. The first is their concern with stagnant food production in underdeveloped economies. Hayami and Ruttan, Sen, Boserup, De Janvry, and others, are predominantly worried about the causes of productive capacity falling behind demand. Hayami and Ruttan for example, point at the lack of "agreement (among agricultural development economists;HR) regarding the processes by which rapid productivity and output growth can be achieved in the agricultural sector". (Hayami and Ruttan, 1985:2)

The second motive is a completely reversed one: authors like Cochrane, Heady, Johnson and De Hoogh are primarily concerned with the continuing tendency of agricultural surplus production in modern Western economies.

This dual orientation, however, does not confront us with serious analytical difficulties. For one thing, most of the economists implicitly if not explicitly refer to a sort of common package of analytical tools, that is, they all direct themselves to the relationships between production/supply and consumption/demand, to the prices of factors, production means and products, and to productivity and profitability. In other words, despite their rather antagonistic orientation, it still seems useful to reduce them to one denomination.

This being said, two marginal notes must be made. First of all, theories aimed at explaining retarding food production in underdeveloped economies can obviously not be used when the agri-

1) This observation has several far-reaching consequences. One of them is that modern primary agriculure has become quite vulnerable with regards to its surrounding 'agencies': delivering and processing firms. Given this relatively weak position, it becomes the more important to react as swiftly as possible to changes in market conditions as these are expressed by the manifold relationships with these agencies.

cultural sector of Western economies is concerned and vice versa. Hayami and Ruttan are quite careful at this point, but the very fact of their prudence deserves attention.

Secondly, although the analytical tools may be rather universal among economists, they do not all start from the same theoretical scope, that is, the "general" economists as well as their agricultural colleagues can be subdivided into "schools", although the criterions for any such subdivision can vary to a great extent 1). Thus, when viewed from a very broad perspective, we can distinguish a school which is directed primarily at analysing relations of political and economical power within society, and a school which above all is concerned with analysing market processes. These two schools are often referred to as "political economy" versus "neoclassical economy". Or, we could set the equilibrium approach against the school which starts its analysis with the presumption of disequilibrium as being the reigning trend within economies.

We could proceed on this subject for much longer, but that would be beyond the scope of this study. The crucial point however is that disagreements among economists can to a certain extent be traced back to fundamental differences in approaching and even defining economic affairs. This counts for general (macro-) economic theory in particular, but some discussions among agricultural economists are also in fact discussions among schools. (Notwithstanding the fact that in the latter case the contrasts often are not as clear-cut and omnipresent as is the case in the former.)

3.3 The friendly debate

Generally speaking it seems hard to find completely opposing opinions on the causes and effects of technical change in agriculture. Yet, technical change in the course of time has become a controversial subject matter, leaving enough room for major disagreements. But the "debate" remains of a rather friendly nature. In the following paragraphs several opinions from a selected number of agricultural economists will be summarized, as well as those stemming from some other disciplines. Within the mainstream of agricultural economic theory we can distinguish "regular" views, and "provocative" variants, that is, comments and criticism on the regular views largely without questioning their general framework.

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1) See, e.g. Cole, et. al. (1983) and Harris (1978) for further elaborations upon schools in general economic theory. For agricultural economic theory, especially in France, see Petit 1980.

3.3.1 Regular views

3.3.1.1 Heady

As far back as 1949, Heady wrote a very noteworthy article on technological change in agriculture. The starting point of this remarkable article is the striking importance that Heady attaches to "socialized services" in the "uncovering" of agricultural innovations and the speeding of their adoption. In other words, public investments in agriculture - especially those in the spheres of research and extension - perform a crucial role in agriculture's development capacity. Subsequently, Heady examines the nature of technical change in agriculture and derives from this its welfare consequences.

As far as its nature is concerned, technical change has the inevitable propensity to increase output (from a given input) or decrease input (for a given output). And in the aggregate, an innovation is always output-increasing since

> *"..although it may result in the same output from a smaller resource input by a given firm or industry, it frees resources for output expansion in other industries."*
> (Ibidem:296)

Still, one has to distinguish between biological and mechanical innovations: although both types of technical change tend to lower the per unit cost of production, the first above all increases output and total costs, whereas the second lowers total costs of production. In assessing the effect of technical change on agricultural income and welfare, this distinction appears to be quite influential. For the income effect depends on three factors:

a) The price elasticity of demand (above or below unity);
b) The extent to which output is increased; and
c) Whether total costs are increased or decreased.

Combined with the two types of innovations, this leaves us with six possible situations (see figure 3.5) 1).

But when taken into consideration that the price elasticity of demand is likely to be below unity, the number of relevant situations is reduced to five. Furthermore, Heady (1949:301) proceeds,

> *"... available evidence indicates that aggregate farm technological advance has been of an output-increasing and likely of a cost-increasing nature (..)."*

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1) Whereby it must be assumed that this elasticity of demand is not influenced by rising or declining product prices.

Situation	Physical characteristics	Predicted effect on net revenues
Demand elastic; total output and total cost increasing innovation	Biological	Net revenue may or may not increase *)
Demand inelastic; total output and total cost increasing innovation	Biological	Will decrease
Demand elastic; total output constant and total cost-decreasing innovation	Mechanical	Will increase
Demand inelastic; total output constant and total cost-decreasing innovation	Mechanical	Will increase
Demand elastic; total output-increasing and total cost-decreasing innovation	Biological mechanical	Will increase
Demand inelastic; total output-increasing and total cost-decreasing innovation	Biological mechanical	May or may not increase **)

*) Net revenue will only increase when total revenue increases more than total costs.

**) A decrease of net revenue will occur when the decrease of total costs is less than the decrease of total revenues.

Figure 3.5 Effects of mechanical and biological innovations under different economic circumstances
Source: Jensen (in Heady et al., 1958:212)

Logically, Heady states technological advance in the U.S. in the first half of the twentieth century, to which the "evidence" refers, to be essentially biological of nature 1). Moreover,

1) This obviously contradicts the general view of agricultural development in the US. It must be noted therefore, that Heady's analysis refers to a period (1910-1946) in which indeed the 'mechanical' path was about to be superseded by the 'biological' and that Heady reserves the term 'mechanical' for those innovations that do not change "the physical outcome of the plants or animals to which it may apply". (Ibidem:296-297).

during this period technical change has been biased considerably in a "land-embodying" - i.e., relatively more land is needed for a given output - "labor-rejecting" and, although only slightly, capital-saving direction. Having arrived at this point of his analysis, Heady formulates three separate alternative goals for public sponsoring as far as technical change in agriculture is concerned (which enables us to switch from "effect" to "cause" again).

The first goal could be an increase of the "total net income" of the farm sector. In that case, "society" should only stimulate those output-increasing innovations where the product concerned has an elastic demand (or the cost reduction should be large enough to compensate for inelasticity). Since Heady characterized mechanical innovations as having no impact upon total output, this type of technological advance should be stimulated whatever the degree of elasticity. In addition, research and development ought to be directed primarily at increasing demand elasticity, e.g. through developing "new industrial uses for farm products". (Ibidem:308)

A second goal could be to increase or maximize "the total welfare of individuals now in the agricultural industry". Under this goal, research and development should above all be directed at applicability to smaller farms and/or in low-income areas. Finally, publicly financed technical change may be aimed at maximizing economic progress in general, which calls for,

> *"..both lower total farm returns and total welfare of people on farms in order that the pricing system might effect a transfer of resources to non-subsistence industries. In order that resources be driven out of agriculture, any increments in income from some innovations would have to be more than offset by decrements in income by other innovations."*
> (Ibidem:309-310)

This "progress goal" should stimulate output-increasing innovations irrespective of demand elasticities, and their land-embodying, capital- or labor-saving nature; in this perspective, land is apparently the limiting factor of production, whereas both labour and capital adjust neatly to this change in economic exigencies. Thus, *"progress becomes characterized by low returns on resources in agriculture"*. (Ibidem:310)

Understandably, Heady argues, this third alternative has been the one "chosen" in actual public policy. The logical consequence of the progress goal would be a sort of two-tier policy, which both stimulates maximum technical change on the one hand and creates maximum provisions for the transfer of resources as well 1). Whether this progress policy can also be identified with

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1) For that matter, Heady believed this second 'track' to be poorly developed in actual policy. See Heady (1949:314 and further), and (1952:827).

a welfare policy (viewed from the economy at large) depends predominantly on the effectiveness of the second "track": mobility policy. According to Heady, past farm policies have failed in this respect, although he immediately questions the feasibility of a "full scale, innovation-inspired program of compensation" (Ibidem, 1949:313).

Summarizing, Heady has given a rough sketch of the sectoral and national-economic implications of (public-financed) technical change, thereby voicing the opinion, which is shared by most agricultural economists and agricultural scientists in general 1), that technical change is inevitable, that it favours economic growth and that policy should be aimed at stimulating its rate and at compensating for its adverse effects.

3.3.1.2 Schultz

In his book "The economic organization of agriculture", Schultz (1953) formulated three hypotheses explaining the rate at which new techniques of production become available. The first hypothesis states innovation to be a completely unpredictable event, that is, not determined at all by economic forces. The second hypothesis, which actually is a variant of the first, considers technical change to be the product of an institutional and cultural atmosphere in favour of science and technology. Again, new techniques are not the result of economic conditions and motives. The third hypothesis claims a close interrelatedness of science with its socio-economic contributions, thus claiming a strong economic determination of technical change.

Without denying the validity of the first two hypotheses, Schultz (1953:110-111) believed the third to be the most promising one:

> *"It is our contention that a new technique is a valuable (scarce) resource that has a 'price' and that this resource is not given to the community or to the producer as a free good; on the contrary, it entails costs some of which are borne by the community and some by the producers as a price that is paid to acquire and apply the resource. Therefore, a new technique is simply a particular kind of input and the economics underlying the supply and use are in principle the same as that of any other type of input."*

Next to being determined by economic conditions to a certain degree, technical change is, according to Schultz, an essential element in the process of economic growth. Hence, he considered technical change - including improved skills and institutions - to be one of the main determinants of the growth of factor supply

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1) See for example Busch and Lacy (1983:chapter 9).

and of product demand. Schultz calculated these new techniques to account for at least 80% of the productivity increase in US agriculture from 1910 to 1950. (Ibidem:109) (It must be noted, however, that Schultz's calculations were based upon Solow's "unexplained residual" approach.)

Since technical change is not costless, the "production" and "producers "of new techniques have to be considered when explaining this feature. Schultz stresses the role of public agencies in this: he even considers this to be one of the two major differences between agriculture and industry in this respect:

> *"In industry most of this (basic and applied;HR) research is done by the firm (..) In agriculture, by contrast, most of the necessary research is borne on public account."* (Ibidem:112)

In chapter 4 we will find this statement to be somewhat exaggerated, since private research in agriculture is far from absent. However, the thrust of Schultz's argument - the dominance of public efforts in agricultural research as compared to the situation in industry in general - cannot be ignored.

Another interesting observation of Schultz concerns the economic effect of technical change upon the social-economic position of farmers. In fact, this points at yet another difference with industry:

> *"The adoption of new techniques in agriculture has back of it the impelling force of competition, with hundreds of thousands of small firms in a highly competitive relationship, one to another, in production. This situation is in sharp contrast to some parts of industry where research is carried on, and where the number of firms in competition with each other is sometimes so few as to give rise to some imperfections in competition that permit the firm to decide whether to adopt the new technique or postpone doing so."* (Ibidem:112)

Both the endogenous character of technical change and its vast impact on supply and supply conditions, made Schultz argue that all common analytical tools for analysing agricultural supply relations render few results. For as long as technical change cannot be estimated or predicted accurately, supply analysis remains seriously flawed. (Schultz 1956:615)

3.3.1.3 Griliches

In his famous article on hybrid corn (1957), Griliches attempted to clarify the endogenous character of technical change. That is to say, endogenous from an economic point of view. In a footnote, Griliches anticipated - or should we say: invoked - a discussion with sociologists by stating that "sociological" variables,

> *"..tend to cancel themselves out, leaving the economic variables as the major determinants of the pattern of technical change."*
> (Ibidem:522)

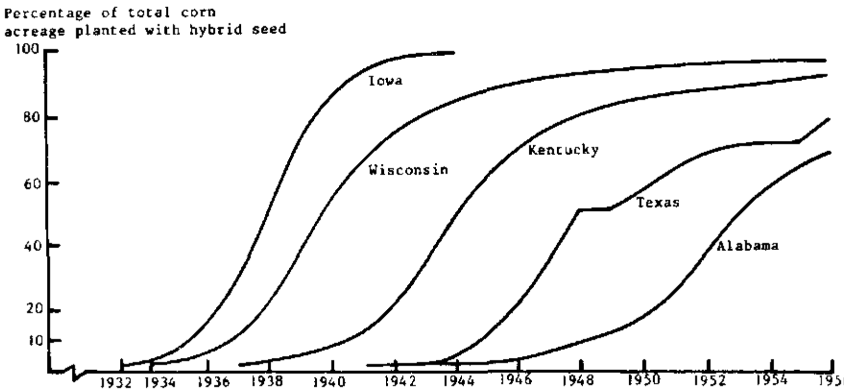

Figure 3.6 Patterns of diffusion of hybrid corn
Source: Griliches (1957:502)

The article "Hybrid corn" essentially deals with explaining the rate and geographical spread of the process of diffusion of hybrid corn, but less with the origin or "production" of this new variety. In fact, Griliches wanted to explain figure 3.6.

Thus, both within and between regions, the adoption of hybrid corn followed a S-shaped curve. But within regions the main determinant was the rate of acceptance, whereas between regions the degree of availability appeared to be the main bottleneck.

Put into one sentence, Griliches' proposition could be formulated thus: the production of hybrid corn by private and public research institutions depends on the pay-off they expect from selling this new corn, whereas the rate of diffusion (or the rate of acceptance) depends on the profitability to farmers of shifting to this new variety of corn 1).

After 1957, no article on the diffusion of innovations in agriculture could be written without reference to the "hybrid

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1) In Griliches' words: "If an activity becomes profitable, there will be money to be made in supplying 'knowledge' about it, and 'knowledge' will be produced." (Ibidem, 1958:605).

corn" article 1). As we have seen in paragraph 2.4.1, soon after the article on hybrid corn, Griliches dealt at length with agricultural inputs in general, that is, with their measurement and economic role. His main thesis was that many attempts to measure inputs were flawed because of a) their neglect or insufficient incorporation of changes in the quality of inputs, and b) their departure from equilibrium assumptions. Consequently, many productivity measurements were "erroneous". From his own, new measurements, Griliches concluded that the growth of total productivity of US agriculture from 1940-1960 could be explained by three factors (Griliches 1963:346):

1. Improvements in the quality of inputs (not only of capital or capital services, but of labour - through education - as well). This would account for about one-third of the measured productivity growth;
2. "Underpriced" capital (services) and the moving out of agriculture of a relatively superfluous and therefore "overpriced" part of the farm labour force. This would explain about 25% of productivity growth;
3. The remainder (over 40%!) by the expansion in scale of the average farm 2).

We have already briefly discussed the contributions of Griliches, together with Jorgenson, to the general debate on productivity measurement. These, as well as the more agrarian oriented articles, have made Griliches one of the most influential and hard to circumvent economists on technical change.

3.3.1.4 Hayami and Ruttan

The problematic feature of Griliches' unraveling of the "unexplained residual" however, is that the mere adjusting of statistics does not tell us how, that is, through what kinds of economic mechanisms technical change takes place. Through their "Agricultural development" Hayami and Ruttan have become well known for their attempts to answer this question by means of research into the causes of international divergencies of agricul-

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1) In 1980, Dixon confronted the statistical material and findings of Griliches' article with "more recent data and improved estimating techniques". Its results were "surprisingly" supportive of the 1957 article (Dixon, 1980).
2) We could add to this third factor the contention of Van den Noort (1966:789) claiming increases in scale to be enabled by innovations to a large extent.

tural productivity 1).

Long before they undertook this task, Ruttan had already proved himself as a student of technical change. In 1956 for example, he calculated the (future) contribution of technical change to gross output in agriculture from 1950 to 1975. The 1975 projection indicated that a) under the "very rapid technical progress" scenario, more than one-third of output growth would be accounted for by technical change and b) a high degree of substitution existed between technical change and capital inputs and current expenses. (Ruttan 1956:65)

Unfortunately, Ruttan was not very clear on the meaning of techn(olog)ical change in this article. His measurements concerned the increase of output per unit of input, and the ways in which technical change manifests itself - as distinct from investments or capital inputs - remained rather vague. In an article from 1960 he was more precise on this subject and even formulated a few of the main ingredients of "Agricultural development". Thus, he complained that although it was generally accepted that scientific and institutional innovations usually precede technical change,

> *"(t)he nature of the processes by which such innovations are generated are but partially understood."*
> (Ibidem:736)

In addition, Ruttan paid attention to the role of agribusiness in the process of technical change, a subject which is often overlooked. According to Ruttan, farm supply industries function as a channel for new techniques and methods of production, thus increasing the dependency of agriculture on the "non-farm" sector of the economy and decreasing its dependency on land.

And with regard to his initially rather vague treatment of technical change as opposed to productivity change, he now stated:

> *".. how to separate the effects of changes in technology from other factors which change the level of output obtained from a given level of total input. With either approach (using partial or total productivity indexes; HR) bias may be introduced:*
> *(a) if the firm, industry, or economy is not operating at equilibrium in both (compared;HR) periods;*
> *(b) if the prices of factors relative to each other and/or*

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1) This book, which carries as subtitle 'An international perspective', has been published in two versions: one in 1971 and a revised one in 1985. The latter version contains more recent empirical material and views (in particular on institutional innovation).

the prices of products relative to each other do not remain unchanged;

(c) if constant returns to scale do not hold; and

(d) if technological change is non-neutral."
(Ibidem:744)

Ruttan's collaborations with Hayami resulted, among other things, in "Agricultural development". This is primarily a book on the theory of "induced innovation", a theory which is borrowed from the British economist J.R. Hicks (Cf.2.3.2 and 2.4.2). Hayami and Ruttan elaborated the induced innovation thesis for three reasons:

1. Too often innovation is regarded as not belonging to the realm of economic science. The process of innovation or technical change is typically called "exogenous". Hayami and Ruttan attempted to prove the fallacy of this proposition;
2. Developments within agriculture are often considered from a national or macro-economic framework (for example, the contribution of agriculture to economic growth), without sufficient or satisfying explanations for these developments themselves.
3. Existing theories on induced innovation (for example, by Hicks, Salter, and Schmookler) appeared to solve the above mentioned problems. But a more agrarian oriented theory of induced innovation was still missing.

Their main hypothesis, which in fact reflects their whole work, runs as follows:

".. a common basis for success in achieving rapid growth in agricultural productivity is the capacity to generate an ecologically adapted and economically viable agricultural technology in each country or development region. Successful achievement of continued productivity growth over time involves a dynamic process of adjustment to original resource endowments and to resource accumulation during the process of historical development. It also involves an adaptive response on the part of cultural, political, and economic institutions in order to realize the growth potential opened up by new technical alternatives.(..)
The state of relative endowments and accumulation of the two primary resources, land and labor, is a critical element in determining a viable pattern of technical change in agriculture.(..)
Agricultural growth may be viewed as a process of easing the constraints of land on production imposed by inelastic supplies of land and labor. Depending on the relative scarcity of land and labor, technical change embodied in new and more productive inputs may be induced primarily either (a) to save labor or (b) to save land."
(Ibidem 1985:4;my accentuations, HR)

The thrust of their argument can be illustrated by figure 3.7. Hayami and Ruttan present this as "a model of induced technical change". I* represents an "innovation possibility curve", an isoquant corresponding to all possible methods or techniques of production, for example types of harvesting machinery (left figure) or varieties with different fertilizer responsiveness (right figure). I stands for a certain type of (already invented) technology. The subscribed numbers indicate the time of invention of these new techniques and/or methods, where I0 represents the starting-situation. To each factor price ratio belongs a certain technology: at BB or bb, I0 will be invented. P and p represent optimal combinations of land, labour and fertilizer. Now, when scarcity relations change, this will be translated in changing price ratios and consequently in the invention of a new technology (which causes both I* and I to shift) 1).

We will highlight two major elements from the elaboration of this induced innovation hypothesis:

- the international comparisons of productivity ratios, and
- the incorporation of institutions, that is, the theory of induced institutional innovation.

For 1960 and 1980 Hayami and Ruttan compared 44 countries regarding two productivity ratios:

a) Labour productivity, that is, agricultural output, measured in "wheat units" (one wheat unit equals one metric ton of wheat) per male worker;
b) Land productivity, that is, agricultural output per hectare. In addition, the land-labour ratios were compared.

From this comparison a few interesting conclusions can be drawn (see also figure 3.3). First of all, we can indeed observe a wide variety of productivity ratios: labour productivity data range from practically zero in a number of countries to over 200 in countries like Australia, New Zealand and the United States. Likewise, land productivity goes from almost zero (e.g.,

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1) Thirtle (1985:3) pointed at a shortcoming of this way of presenting the matter: ".. the diagrams must represent some production relationship which cannot be functionally separable since land appears in both diagrams. It follows that the specification of the land/labour tests used by Hayami and Ruttan is incomplete, since changes in the land/labour ratio caused by the substitution of fertiliser for land are ignored." And Nordhaus (1969) remarked that these diagrams implicitly assume Harrod neutrality (see 2.3.3.2), which was to be explained...
2) It should be born in mind that these productivity ratios are expressed in metric tons of wheat units. Thus, Australia's land productivity was estimated to be about 0.09 metric tons of wheat per hectare in 1960 and 0.15 in 1980, both figures being the lowest of all countries considered.

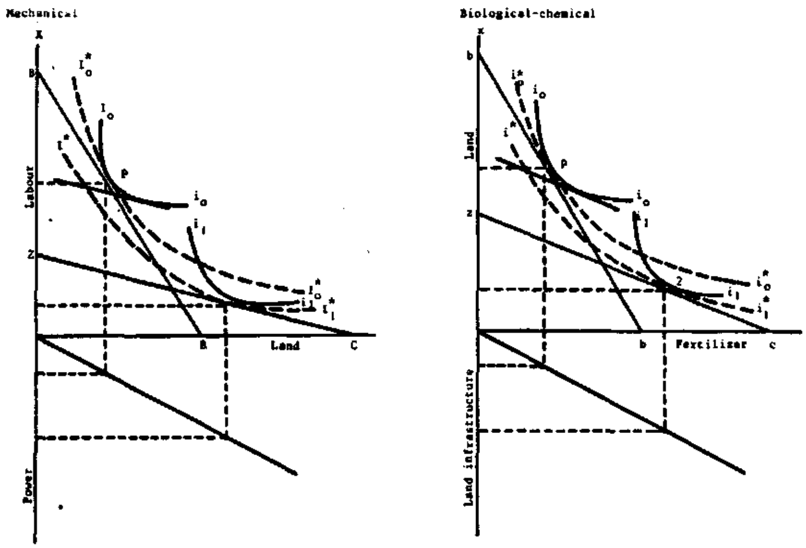

Figure 3.7 A model of induced technical change in agriculture
Source: Hayami and Ruttan (1985:91)

Australia!) to over ten (e.g.,the Netherlands and Japan) 2) and land-labour ratios range from about 0.5 (Egypt, Bangladesh) to 1764 hectare per male worker in Australia (1980).

Secondly, despite these differences, there is an international tendency towards both higher increases in labour productivity relative to land productivity as well as an increasing land-labour ratio. Several underdeveloped countries showed the opposite trend (for example, Egypt and Bangladesh), which brings us to a third conclusion: when classifying the 44 countries according to their national economic performances, we notice striking differences in the productivity data between developed and underdeveloped economies. Table 3.1 indicates this clearly.

At this stage of their analysis, Hayami and Ruttan attribute a crucial role to the economy "surrounding" agriculture, or to be more precise, to the over-all process of industrialization. The influences of industrialization upon agricultural development can be manifold:

- it increases demand for farm products;
- as a result of an increasing division of labour, specialization and the usage of new methods and techniques of production, the costs of many (modern) agricultural inputs will decrease;
- a more favorable factor-product price ratio will stimulate demand for inputs by farmers;
- it increases demand for labour in the non-farm sector; (Ibidem, 1985:132).

Table 3.1 Comparisons among country groups of agricultural output per male worker (Y/L), and labour-land ratio (A/L), 1960 (1957-62 averages) and 1980 (1975-80 averages)

	Developing countries (DC)			Middle-stage countries (MC)	Less developed countries (LDC)
	Average	New continent	Other		
Labor productivity					
1960	41.0	97.5	31.4	9.9	4.7
1980	116.1	240.1	92.8	23.9	6.4
Land productivity					
1960	2.20	0.48	3.53	0.76	1.04
1980	3.29	0.70	5.30	1.33	1.61
Land-labor ratio					
1960	18.6	205.4	8.9	13.1	4.6
1980	35.3	342.0	17.5	18.0	4.0
Growth rate, 1960 to 80 (%/year)					
Y/L	5.9	5.1	6.0	5.0	1.7
Y/A	2.3	2.1	2.3	3.2	2.5
A/L	3.6	2.9	3.8	1.8	-0.8

Source: Hayami and Ruttan (1985:123)

Consequently, Hayami and Ruttan proceed, a proper responding by farmers to these altering economic conditions - as expressed in particular in changing factor and product prices and their ratio - is "critical to the agricultural development process". From these considerations, Hayami and Ruttan have constructed their own version of a "metaproduction function": a "potential production function", reflecting "the envelope of commonly conceived neoclassical production functions" and resembling the innovation possibility curve that was dealt with earlier. The meaning of this metaproduction function is expressed as follows:

> *"This adaptation (to a new set of factor and product prices;HR) involves not only the movement along a fixed production surface but also the creation of a new production surface which is optimal for the new set of prices."*
> (Ibidem, 1985:133,my emphases;HR)

By means of illustration, Hayami and Ruttan constructed a diagram of the relation between fertilizer input and the yield response, as shown in figure 3.8.

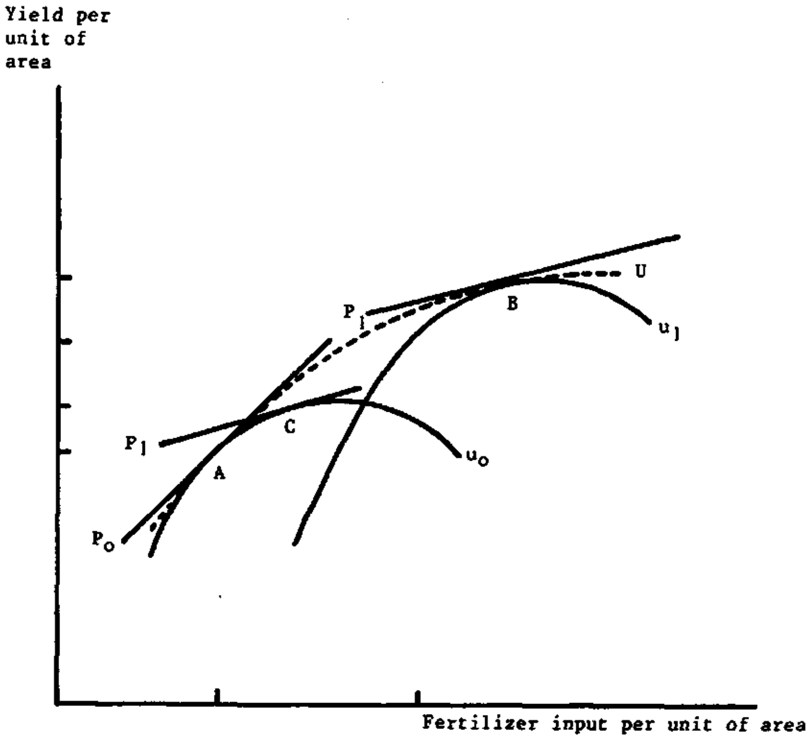

Figure 3.8 Shift in fertilizer response curve along the meta-response curve
Source: Hayami and Ruttan (1985:134)

The lower case u represent the fertilizer response of current (u0) and improved varieties (u1). A decline in the price of fertilizer (reflected in the shift from P0 to P1) shows the yield responsiveness of the current variety to be smaller than that of the improved variety. By constructing response curves for several varieties, a metaproduction curve (U) can be drawn.

Whereas this metaproduction function is not stable over time, and instead related to "the accumulation of general scientific knowledge", Hayami and Ruttan hypothesize that,

> *"..the agricultural productivity gap among countries is based on differences in the prices of modern technical inputs in agriculture and differences in the stock of human capital capable of generating a sequence of innovations which enables agriculture to move along the metaproduction function in response to changes in factor and product price relationships."*
> (Ibidem 1985:137)

This hypothesis is the underlying view of their international comparisons mentioned above. Nevertheless, more thorough evidence is given in their study of the long-run development of agriculture in the United States as compared to Japan, a study to which we referred earlier. Over the past 100 years, US agriculture followed a "mechanical" path of development whereas Japan followed the "biochemical" path, notwithstanding a trend of convergence over time.

This differential development of US vis-à-vis Japanese agriculture can, according to Hayami and Ruttan, best be understood as the result of a "dynamic factor substitution process", with each country starting from different resource endowments and, consequently, different ratios of factor prices. Thus, in Japan the ratio of land prices to farm wages was high relative to that in the US. And because of the combination of low fertilizer prices (relative to land prices) and biological innovations which made fertilizers more lucrative, Japan started its "biological" path long before the US did, where similar circumstances reigned only much later (from 1930 and on).

Self-evidently, these international comparisons can meet the "apples and pears" problem: in case of such differences, is it indeed allowed to draw analytical conclusions? By means of various regression analyses 1), Hayami and Ruttan claim this to be the case:

> *"The results (..) seem to suggest that, despite enormous differences in climate, initial factor endowments, and social and economic institutions and organizations in the United States and Japan, the agricultural production function, the inducement mechanism of innovations, and the response of farmers to economic opportunities have been essentially the same."*
> (Ibidem 1985:187;my underlining)

Nevertheless, the analysis is not complete, for Hayami and Ruttan's hypothesis of induced innovation has not been confirmed yet, since the differential developments might as well be the result of pure factor substitution, without any technical change taking place. On the other hand, there may be some biasedness of technical change involved. Above all, biasedness ought to be related to (changing) factor price ratios. Whereas a meaningful review of the statistical methods and techniques that Hayami and Ruttan employed would almost require its reproduction 2), we will

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1) Namely of land-labor and power-labor price ratios, and fertilizer input per hectare of arable land on relative factor prices in both countries for 1880-1980. See Hayami and Ruttan (1985:182-185).

2) See Hayami and Ruttan (1985:187-197).

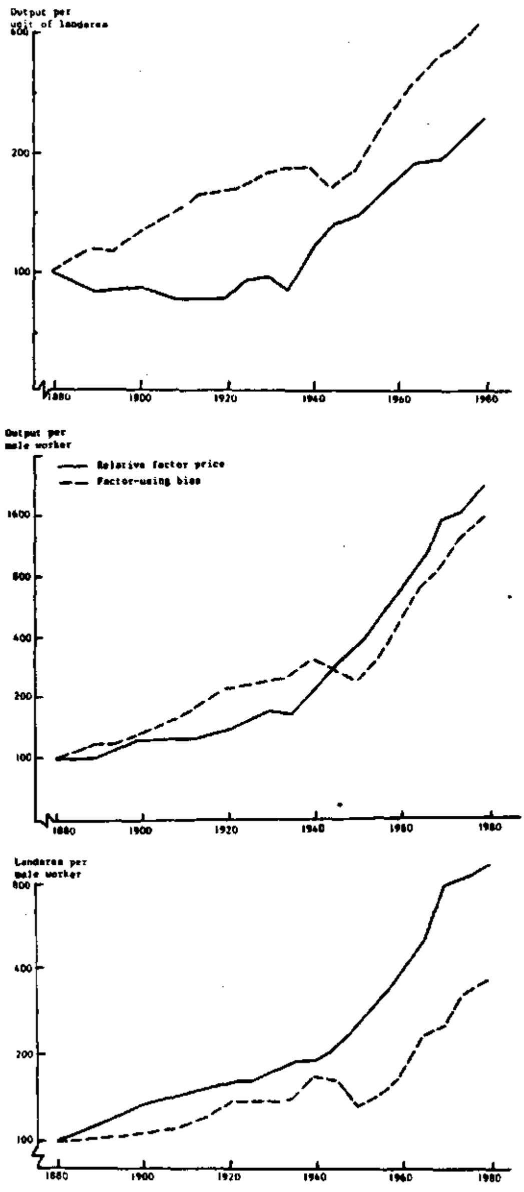

Figure 3.9 Individual comparisons between the indexes of factor-using biases in technical change, and the indexes of factor prices relative to the aggregate input price index, US, 1880-1980

Source: Hayami and Ruttan (1985:193)

confine ourselves to their main finding, that is, that in both countries and in most cases, there was a (negative) relationship between a factor-using bias and relative factor prices. Figure 3.9 summarizes the statistics and illustrates the validity of the induced innovation hypothesis.

Thus, except in the case of land 1), there is a significant commensurability between price movements and biases. For example, the labour-saving bias (downward sloped curve) goes together with a rising relative labour price. The resemblance between these U.S. figures and those for Japanese agriculture is striking indeed (Ibidem:194).

Perhaps the most "innovative" feature of Hayami and Ruttan's efforts is the great stress they place on the impact of institutions and on institutional innovation. They call for an approach which considers institutions to be part of the economic system and therefore both influencing, and influenced by other economic phenomena:

> *"In the area of economic relations (institutions) have a crucial role in establishing expectations about the rights to use resources in economic activities and about the partitioning of the income streams resulting from economic activity."*
> (Ibidem:95; my accentuation, HR)

Hayami and Ruttan hypothesize that the behavior of institutions can be explained fairly well by the same inducement mechanism described above. As a matter of fact this proposition is unavoidable because of the crucial role that is attributed to institutions in the process of agricultural development: if the latter can be characterized by the induced innovation mechanism, the first can undoubtedly not escape from it. Thus, the authors depart from the following, rather bold, assumption:

> *"Farmers are induced, by shifts in relative prices, to search for technical alternatives that save the increasingly scarce factors of production. They press the public research institutions to develop the new technology and also demand that agricultural supply firms supply modern technical inputs that substitute the more scarce factors. Perceptive scientists and science administrators respond by making available new technical possibilities and new inputs that enable farmers profitably to substitute the increasingly abundant factors for increasingly scarce factors, thereby*

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1) Hayami and Ruttan comment on the peculair behavior of the land-using bias that this is to explained by the endogenous character of land as a production factor.

guiding the demand of farmers for cost reduction in a socially optimal direction."
(Ibidem 1985:88)

Of course, reality looks a lot more complicated, and Hayami and Ruttan immediately add to this that there can be said to exist a "dialectic interaction" among farmers and institutions and that the heterogeneity of agriculture - e.g.,"small" versus "large" farmers - may cloud this image somewhat. Still, they hold incomplete or blocked interaction responsible for the failure to develop agriculture in several cases 1). We will return to this matter later as well as to some comments on Hayami and Ruttan's induced innovation approach. To conclude with, it is not for nothing that we have paid considerable attention to Hayami and Ruttan. Their collaboration resulted in very thorough analyses of the inducement mechanism with regard to technical change in agriculture.

Comments

Nevertheless, some serious draw-backs must be added to this review. The first is that their rather large-scale approach can probably not be applied easily to local and short-run problems 2). Secondly, if it is true that scarcity relations perform such a crucial function, it would have been no more than logical when Hayami en Ruttan had spent more energy in trying to explain both the condition and the development of scarcity 3). Thirdly, governmental price and market policies in western economies hardly receive any attention for their role in the explanation of convergence and divergence in agricultural development.

Perhaps the most serious draw-back, however, is that the emergence of new techniques still is a mysterious affair in "Induced development": innovations are simply induced which means that economic variables turn out to be a very powerful - or even the only - ex-ante selective device, to say it in Dosi's terms 4). The state of the art, existing purely technical bottlenecks, and the prevailing paradigms and trajectories apparently pose no problem at all, since these aspects are thought to be overruled by the exigencies of the market. The institutional "new shoot" of their theory is clearly too tentatively and optimistically formulated to provide an explanation for both the first stages of technical change and the "dialectical interaction" between science, institutions and economic variables.

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1) See Hayami and Ruttan 1985: Part V. The cause of this phenomenon, according to Hayami and Ruttan, is often located in the (improper) functioning of the market mechanism.
2) Cf. De Groof (1977:128).
3) Cf. De Hoogh (1978).
4) See for example Biggs and Clay (1981:323) and Schmitt (?:16).

3.3.1.5 Binswanger

As a frequent collaborator of Hayami and Ruttan, Binswanger is known for his efforts in testing and highlighting the induced innovation hypothesis. Before elaborating hereon, it is useful to mention that Binswanger in fact subscribed Heady's opinion (see paragraph 3.3.1.1):

> *"Agricultural technical change increases national income and turns terms of trade against agriculture, which increases demand for agricultural commodities. But the increase in demand for agricultural products is not sufficient to offset the resource-saving per unit of agricultural output made possible by technical change. Therefore, technical change in agriculture pushes labor out of that sector into the non-agricultural sector, where its marginal productivity is higher."*
> (Binswanger, 1978:112)

In an article published in 1977, Binswanger started by stating that, in the absence of research, the factor intensity of the agricultural sector depends on,

a) the choice of the commodity output mix, and
b) the choice of technique for each commodity.

He argued that research will affect both these choices and in addition, that research activities will be conducted according to the induced innovation thesis:

> *"..the researcher chooses the combination of research lines which leads to the maximum reduction of costs of production at existing factor prices. (..) If (the 'research resource allocator';HR) makes his research resource allocation decision on the basis of expected profits from a research project, he will automatically tend to favor those research lines which either favor the high priced commodity or save the high-priced factor."*
> (Ibidem, 1977:527)

Evidently, this is the theoretical ideal-type situation again. To test its validity Binswanger compared both the "technical change paths" of six countries and the measured biases of technical change in US agriculture. In both cases the interaction of price movements with (aggregate) factor shares and/or ratios was the ultimate object, although the second ("many-factor") test included all relevant prices, whereas the first ("two-factor") only took land and labor prices into account. Not surprisingly, the first test - in which the development of agriculture in the USA, Japan, the UK, France, Germany and Denmark is examined - showed extensive differences in "paths" of technical change. And indeed (the story is becoming monotonous) differences in factor scarcities explain a good deal 1). Of more interest, however, is the many-factor test of US-agriculture in which the shares and prices of land, labour, machinery, fertilizer and other factors have been compared, resulting in the establishment of significant biases in technical change as shown in figure 3.10 2).

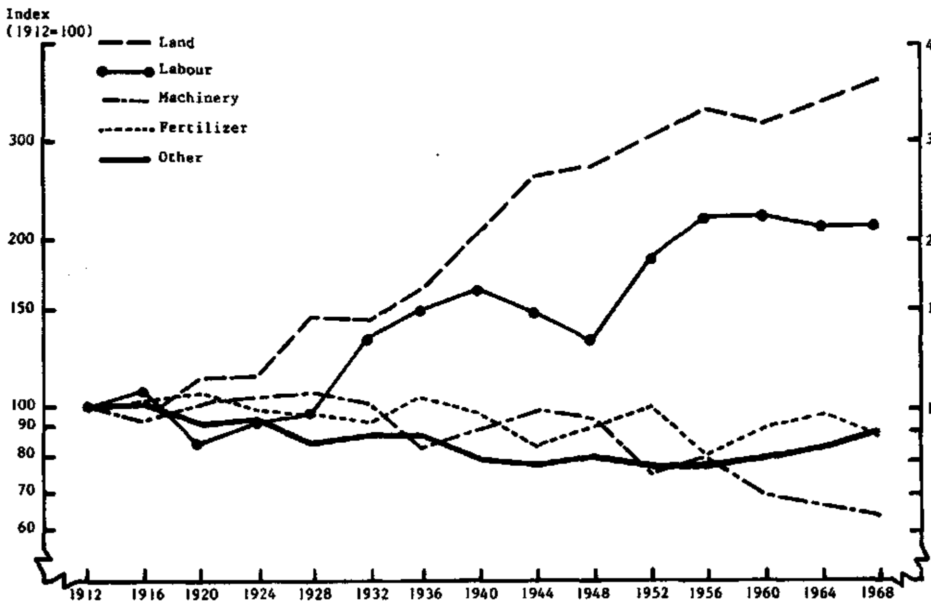

Figure 3.10 Indices of biases in technical change, US agriculture, 1912-68
Source: Binswanger (1977:546)

This figure is to be interpreted as follows: each line represents the ratio between the series of S'it and Sit, where the S'it-series signify the shares of factors i (land, labour, etc.) which would have developed from 1912 until 1968 in the absence of

1) With the reserve that the European path, relative to the one in the US, has been less labour-saving than was to be expected from theory.
2) The prices of land cannot be of much relevance because of their largely endogenous character. (Binswanger, 1977:541).

factor price changes (price-corrected factor shares), and the Si, 1912-series stand for the actual shares of i. A positive slope of the line then represents a factor-using bias, whereas a negative slope indicates factor-saving to be the case. For an increasing ratio signifies a positive divergence between what factor shares would have been without price changes, and what they actually have been (Binswanger, 1977:218-220). Thus, after the Second World War a strong labour-saving bias existed, whereas technical change was more or less neutral with respect to labour before that period. This corresponds with the observation that especially after 1945 wages rose at a much faster rate than before.

However, in the case of machinery, which shows a strong using bias from 1928 onward, prices rose as well and even accelerated after World War II. Binswanger (1977:544): "Innovation possibilities must have been machinery using regardless of the role of factor prices in determining biases". The fertilizer case, on the other hand, is consistent with the assumption of neutral innovation possibilities and thereby with the induced innovation hypothesis: the declining trend of fertilizer prices is accompagnied by a strong fertilizer-using bias. A final noteworthy result concerns the time lag between drastic price changes and the occurrence of biases. In the case of labour (after 1945) it took about six to ten years for the bias to emerge, and in the case of fertilizer it took about six years. These findings correspond to those concerning the time lag between the initiation and the materialization of agricultural research (Ibidem:545).

3.3.2 Provocative variants

Unlike the many debates within general economic theory, debates among agricultural economists are seldom being conducted in terms of dogmas. Nevertheless, disagreements among agricultural economists do exist. Although this has already been illustrated somewhat in the previous paragraph, we will now add a few more critical contributions by agricultural economists who are somewhat more inclined to challenge the general framework of analysis.

3.3.2.1 Cochrane

"The engine of modern farm production is farm technological advance", Willard Cochrane (1956:46) stated in his popular book "The city man"s guide to the farm problem". Saying "Cochrane" is like saying "treadmill theory"; in his view modern agriculture is developing very fast in terms of production and productive capacity, while at the same time remaining stationary in terms of social-economic performance:

> *".. the innovators reap the gains of technological advance during the early phases of adoption, but after the improved*

technology has become industry-wide, the gains to innovators and all other farmers are eroded away either through falling product prices or rising land prices or a combination of the two, and in the long run the specific income gains to farmers are wiped out and farmers are back where they started - in a non-profit position. In this sense, technological advance puts farmers on a treadmill."
(Ibidem:66) 1).

The most attractive feature of this treadmill theory probably is its inherently "closed" character, for, to give an example, there is hardly any room for an analytical distinction between the economic causes of technical change and its effects. Both are intertwined to a large degree. Futhermore, obviously, this theory links technical change to the economic structure and performance of the agricultural sector, thus firmly establishing its endogenous character.

In reviewing Cochrane's theory, we will let him answer two questions: 2)

1. What is technical change and where does it come from?
2. What is the role of government support in agriculture with regards to the treadmill-effect?

As already stated much earlier, Cochrane used a very simple definition of technical change, reading as follows:

"..an increase in output per unit of input resulting from a new organization, or configuration, of inputs where a new and more productive production function is involved."
(Cochrane, 1958:46)

In addition, technical change has the inherent propensity of lowering the per unit costs of production 3). In "Farm prices" (1958) Cochrane argued that it has been because of the fact that "society decided to take collective action", that agriculture has

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1) Cf. Ruttan (1981:257).
2) In chapter 4 we will deal more explicitly with Cochrane's view on the role of prices in the process of technical change.
3) Veerman has criticised this assumption because it seems to suggest that the (per unit) costs-decreasing effect of technical change is also in operation in the short-run, whereas, according to Veerman, the necessary adjustments in the stock of capital goods can only take place in the longer run (Veerman, 1983:136). As we have seen, Heady reserves this (cost-decreasing) characteristic of technical change for biological innovations.

ture has found itself in abundant supply of new technologies 1). Although the individual ("typical small family") farmer was not able to conduct much research and development of his own,

> *"..the many small farmers who make up the agricultural industry have rarely organized to promote and finance research and development through their own agencies."*
> (Ibidem:98)

Instead, society, conscious of the importance of an assured supply of food and believing in the virtues of technology, intervened and made agriculture the highly dynamic sector it has become; thus would read Cochrane's answer to the second question. But he would immediately add the complicating influence of agricultural policy. For at this point his treadmill theory becomes of interest. In fact, Cochrane has presented *two versions* of this theory: one that refers to a "free market" situation, and one that refers to a "government support" situation. In both situations however, the treadmill in which farmers find themselves essentially consists of three elements which are narrowly interrelated: technical change, increasing agricultural output, and downward pressure on agricultural prices. Needless to say, there are a lot of ifs and buts in the interrelation between these three features, but basically this is the general idea.

In a free market situation the treadmill will keep on going, with "innovators" constantly reaping the gains - and therefore remaining innovators as long as possible - and "laggards" being pushed out of business.

The government support situation is somewhat different, because in this case the downward pressure on prices is regulated, that is, prices are likely not to fall as much as in the situation of the free market. Consequently, all economic gains are held by all those farmers who manage to stay in business and the distinction between "innovators" and "laggards" obviously is not as sharp-edged as in the former situation. However, Cochrane continues, since these economic gains are being capitalized into land, the benefits "ultimately" go to landowning farmers or landowners in general 2). And as this tends to increase the price of land, previous nonadopters are faced with higher opportunity costs of land and thus inclined to follow the innovators.

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1) To which cochrane adds ironically: "The strange thing of all this is that this generous financing of research and development is all done in the name of helping farmers, and it is so accepted by most farmers and their leaders." (Ibidem:99).

2) Until, ".. unit costs of production are once again equal to price, and there is no profit remaining which is attributable to the technological advance". (Cochrane, 1965:65).

De Janvry (1977) called this the "land treadmill". In addition, output tends to increase faster in the situation of government support, because the price fall which would occur in case of a genuine free market - and would push out many farmers - is blocked to a certain extent:

> *"With no program, the price of the product must fall, and some or all of the gain is wiped out. If prices are supported, the gains of the technological advance are held by the average farmer. Where price falls in the free market, the laggard must adopt or be crushed in the price-cost squeeze."* (Cochrane, 1965:64-65)

There are a number of problems with Cochrane's theory. For example, he does not clarify what makes farmers so special in this respect. That is to say, why should other producers not be caught in such a treadmill? Cochrane's answer might be that the competitive market structure makes the individual farmer a price-taker, as well as a technology-taker. For lowering his per unit costs is his only remedy for declining relative prices. In other sectors the same mechanism may be in operation, but only in sectors with a rate of competitiveness that is comparable to that in primary agriculture. Cochrane himself, however, has hardly dealt with this matter. A second problematic feature of the treadmill theory is that it remains rather descriptive, and hard to test empirically.

In chapter 5 we will return to Cochrane when dealing with points of view on the relation between prices and technological change. So far it suffices to conclude that Cochrane has been one of the few agricultural economists, who placed technological advance, however poorly defined, at the top of his agenda.

3.3.2.2 De Hoogh

In De Hoogh's view, the main developments within agriculture cannot be analysed without considering their interrelatedness with the dynamics and characteristics of the (national) economy in general. Thus, it is his belief that,

> *"when population is growing moderately, at a certain level of welfare a further increase of incomes necessitates a reduction of the number of labourers in agriculture in order to prevent the renumeration of factors of production in agriculture to decline."*
> (Ibidem, 1971:670; my translation,HR)

Likewise, following the Hicksian framework, he locates the primary forces behind technical change in agriculture in the tendency of labour costs to rise relative to capital, the cause of which is only to be found in the economy as a whole. Yet, he adds to the Hayami-Ruttan argument the impact of the typical evolution that occurred in the agricultural sector of most Western economies:

> *"There is, however, a limit to the possibilities of replacing labour by equipment and machinery. For the limit is reached as soon as all wage workers have been replaced; the farmer himself is left as the only labourer. Since his own labour power is immobile as long as he wants to remain in business - it is a fixed cost - it appears difficult to 'mechanize away' his own labour. Whenever this limit is reached, the possibilities to apply existing technologies, in order to save more on labour expenses, actually run dry. Purchasing this (labour-saving;HR) machinery or equipment does not result in cost-reduction on a one-man farm, because the labour of this one person (the farmer himself) simply isn't an item of expenditure he can economize on; instead it is a component of his total income."*
> (Ibidem 1978: 67; my translation,HR) 1)

According to de Hoogh, this "lonely" farmer has three possibilities to raise his level of (relative) income. Firstly, he can increase the economic size of his farm operation in order to be able to apply the appropriate new techniques efficiently. Secondly, he can try to intensify his land use and - consequently - concentrate on applying land-saving techniques. Finally, he can increase the productivity of his labour by (increased) specialization.

Confronted with the history of American agriculture, De Hoogh perceives a turning-point around 1940. For after World War Two, the number of farm-firms began to decline significantly, land prices rose (notwithstanding low profitability of agricultural production) and fertilizers, and other yield-increasing techniques were being applied rapidly and successfully. Figures 3.11a and b illustrate De Hoogh's argument, whereby the latter figure clearly indicates that the average farm size increased sharply from the Fourties until the Eighties. Almost identical figures can be obtained for a great number of West European countries, including the Netherlands (Binswanger and Ruttan, 1978:82-87, and Veerman, 1983:74).

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1) The same argument has been put forward by Van Vuuren (1961:106-107): ".. the increase in labor productivity on small farms is hampered by the fact that no labor can be displaced and that the unit of operation is too small to apply new labor-saving technologies efficiently (..). In order to increase their labor returns additional land must be bought."

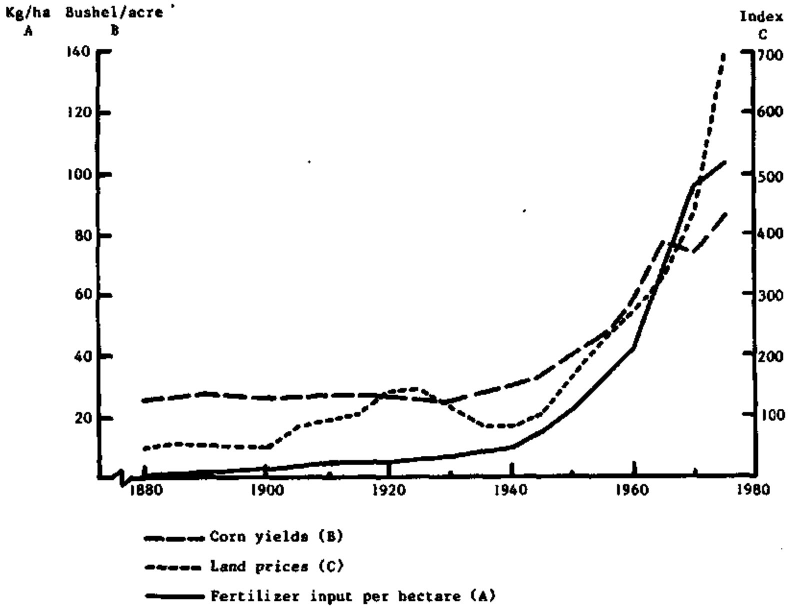

Figure 3.11a Land prices, corn yields and fertilizer input, US agriculture, 1880-1980
Source: De Hoogh (1978)

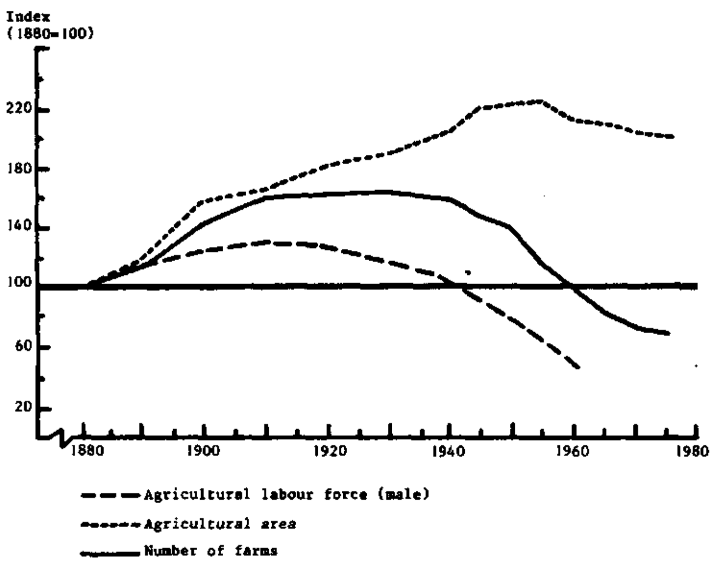

Figure 3.11b Area under cultivation, number of farms and (male) farm population, US agriculture, 1880-1980
Source: De Hoogh (1978)

Thus, De Hoogh touches upon one of the problematic features within standard economic theory: the occurrence of indivisibilities. Veerman (1983) has elaborated this argument in his dissertation on the connection between land prices and technical change in agriculture. He agrees with the indivisibility thesis and, moreover, hypothesizes that differences in the rate of adopting new techniques are the primary cause of rising land prices 1).

Next to his emphasis on the typical development of the farm structure, De Hoogh (1987) - based on a fundamentally positive attitude - has commented on the 'simple' and 'optimistic' character of the induced innovation theory; his main argument is that Haymani and Ruttan would rely to heavily upon the market as an allocative and distributional device, i.e. that they leave little room for 'the indisputable negative effects' of technical change (Ibidem:37).

3.3.2.3 De Janvry

The French/American economist De Janvry has tried to develop a global framework for understanding the process of induced innovation, especially related to the role of institutions 2). In his view, the processes of technological and institutional innovation are "so closely interrelated that any change in one, ultimately presses for change in the other". Thus, he dares to criticize the "neoclassical apparatus" with which Hayami and Ruttan developed their theory. De Janvry regards it as "linear", for it would only leave room for institutional change being induced by technological change:

> *"Moreover, the model in question does not uncover the dynamics of the interrelationships between supply of and*

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1) Uhlin (1985:168) adds to this: "Since World War II, agricultural policy has endeavoured to create family farms with minimum farm sizes that would give the farm family full employment. It is not clear if this has been motivated by economies of size arguments only. Certainly it has meant the *creation* of indivisibilities (labour input) and has consequently been an argument for economies of size." Nonetheless, against this could be argued that the mere existence of *part-time farming* in many western countries strongly mitigates the indivisibility thesis.

2) De Janvry (1977:552) defined institutions very broadly, namely as: "The ways in which people relate to each other in their respective functions in the production process are translated into a set of institions that characterize and establish guidelines for these relationships."

demand for innovations, nor can it articulate the parameters that affect both supply and demand."
(Ibidem, 1977:553) 1)

Instead, the "dialectical model" developed by De Janvry does try to account for dynamics and reciprocity. Nevertheless,

"The central node of the model is a 'payoff matrix' which identifies the net economic gains and losses that are expected to result from the provision of a set of public goods (technological and institutional innovations) to a given set of interest groups in society."
(Ibidem, 1977:553)

Interest groups, in De Janvry's model, are farmers, landowners, farm labourers, industrial employers, urban workers, exporters and government. And each of them "expects to derive a specific income gain or loss from each particular public good"; the totality of these incomes (or losses) constituting the payoff matrix.

By means of illustration, De Janvry has constructed a scheme of the process of inducement and diffusion of innovations, i.e. for as far as these are public goods (figure 3.12).

This scheme has the great advantage of "socializing" the phenomenon of technical change. That is to say, not only does it reveal the many different interests involved, it also contains an alternative for unilinear cause-and-effect treatments of the subject; thus, demand and supply are interrelated, as are - indirectly - the socio-economic and politico-bureaucratic structure. For reason of clarity we should add that the payoffs are determined by the material and economic effects of innovations concerned and their rate and extent of diffusion. Based on this scheme, De Janvry has constructed a framework for a welfare analysis of biochemical and mechanical innovations. Thus, in the case of mechanical innovations - other things being equal - in both the closed and the open (or price-supported) economies, the net social gains are fully captured by landowners, since the "land treadmill" is the basic mechanism of technical change. Only in the case of a closed economy do biochemical innovations affect a completely different distribution of welfare gains: whereas food prices decline, gains accrue to both consumers and employers, the division of which depends on their "relative social power". In an open economy the magnitude as well as the distribution of welfare gains depend on the possibility to increase ex-

1) Ironically, Hayami and Ruttan - indirectly - defended their view by referring to the "traditional Marxian view" stating technological change to be the primary source of institional change (Hayami and Ruttan, 1985:95-96).

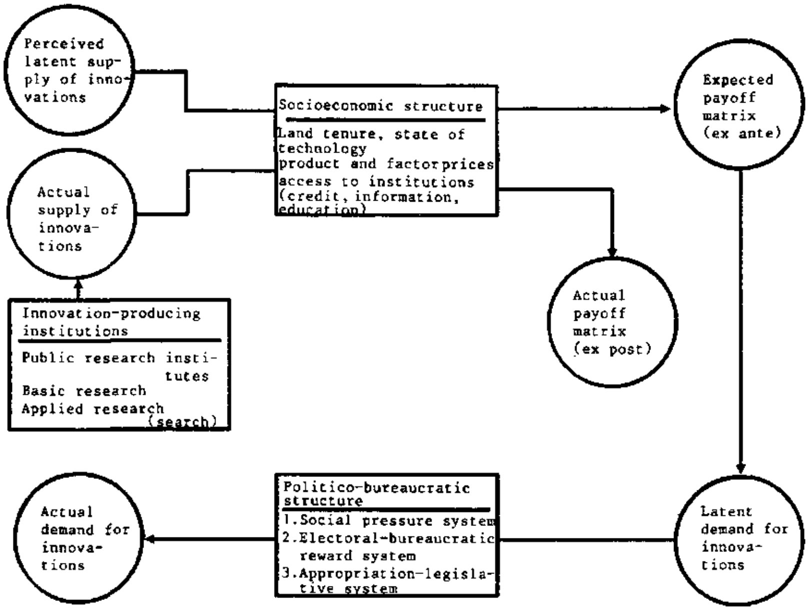

Figure 3.12 Supply and demand for technological and institutional innovations
Source: De Janvry (1978:302)

ports and on the effects on the subsequent improved balance of payments on the economy as a whole. Finally, in the price-support case the net social gains will accrue to landowners through a tax-based income transfer.

All this may appear to be a side-track as it refers primarily to the effects of innovations. However, with the above presented scheme in mind, De Janvry would argue that the question as to who captures the benefits is crucial in understanding the causative elements of technical change:

> *"The politico-bureaucratic structure of society determines how these demands (for technological and institutional changes;HR) are translated into an actual supply of new technologies and institutions. And the socioeconomic structure translates that supply into actual payoffs for each social group."*
> (Ibidem, 1977: 562)

In chapter 5 we will return to De Janvry's scheme. For the moment, it suffices to conclude that the "provocative" views all tend to broaden the scope of the problem, since they explicitly try to incorporate general economic and social forces in their analyses.

3.3.3 A step outside the boundaries of agricultural economics

As we have seen, agricultural economists have become more and more interested in the causes of or influential factors behind technical change. This cannot be said of other agriculture-oriented scientists as these are - at best - more interested in both the possibilities and impacts of new techniques and technologies. From the Dutch scene we will highlight two apparant exceptions. The first concerns a distinct line of thinking within agrarian sociology which can be labelled as the "incorporationist" view. The second concerns the viewpoint of the production ecologist C.T. de Wit, a viewpoint we will call "the agronomic imperative".

3.3.3.1 The incorporationist view

In the late seventies, the rural sociologist Benvenuti constructed the foundations of his so-called TATE-theory, the theory of the Technical Administrative Task Environment of present-day farmers in western societies:

> *"TATE forms with the farm operation a complex network of functional interdependencies which most of the time signify normative, functional and material dependency of the farm unit upon it."*
> (Benvenuti, 1975:49)

Because of the alleged subordination of primary agriculture to these TATE-agencies, we call this the "incorporationist" view. One of the main arguments which is of interest with regards to our subject is that TATE is said to constitute a prescriptive body vis-à-vis the individual farmer, and consequently guides the latter's decision process. Obviously, this also involves decisions concerning investment in new techniques or methods of production, not in the least because of the presence of "technology producers" within TATE. The process of modernization and rationalization - the materialization of technical change at the farm-firm level - is becoming more and more subjected to the control of "agencies" from within TATE. All possible "decision-chains" at the farm level tend to become dependent upon the exigencies and wants of TATE. Benvenuti's TATE, to avoid misunderstandings, exists as a "quasi-organisation", the member agencies of which can be considered to share some common interests or attitudes without this being laid down formally. Two of these common elements are:

- TATE-agencies act "as each other's referee in the interactions with the farm operator;
- there is a(tendency towards) "normative and attitudinal consistency regarding the farm problem". (Benvenuti, 1975:47)

A major hypothesis of this TATE-theory is that the growing incorporation of farms within these institutional networks will tend to homogenize agricultural production; as the individual entrepreneurship diminishes - because of the many dependencies towards TATE - the new entrepreneur or "planner" becomes TATE itself, and the technical-economic performance of farm-firms thereby becomes subjugated to decisions within the network. If true, this has consequences for both the theory and the practice of the innovation process in agriculture. For instance, all "pull factors" (demand for new techniques by farmers) will be or become inferior to "push factors" (supply by TATE-agencies), since these TATE-institutions will be more powerful in directing both the speed at which new techniques become available, and, more important, the kind of techniques that are to be developed and introduced. The conclusion is that, according to the theory, the S-curve of diffusion becomes more and more controlled by TATE.

Unfortunately, these deductions have hardly or not at all been elaborated thus far, for the primary scope of attention has been and still is the consequences of the TATE-phenomenon for the mode of agricultural production, rather than its causes. Recently, Bolhuis and Van der Ploeg (1985) have conducted such a study with respect to patterns of agrarian development in Peru and Italy. Typically, they searched for an explanation of observed differential modes or styles of production within otherwise homogeneous areas 1). These differential patterns, according to Bolhuis and Van der Ploeg,

> *"... are not fortuitous, but (..) the outcome of deliberate organized styles of agrarian practice, each in itself carrying with it a rational coherence of ends and means, a valid developmental path from the management point of view, and a careful coordination between firm organization and firm administration. Peasant labour is structured in different manners (according to strongly diverging calculations 2): the systematically differing styles of agrarian practice and the concomittant differences in productive outcomes are the result."*
> (Ibidem:396; my translation;HR)

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1) That is, homogeneous in an economic sense (no substantial differences in relative factor prices), in an institutional and technologcial sense (al farmers having the same degree of access to institutions and technology), and in an ecological sense (all farmers facing the same ecological conditions) (Bolhuis and Van der Ploeg, 1985:27).

2) The authors' term is "calculi", which is somewhat broader than 'calculations', as it refers to the decision process in general. Economists would be more inclined to use the term "incentives" (on which managerial decision are based).

Bolhuis and Van der Ploeg perceived two dominant extremes within the broad range of observed patterns. On the one hand the scale-increasing and relatively extensive style, and the relatively intensive style on the other hand. Although it is merely hypothesized in their study, the authors point out that each of these two styles is attended by a specific "technology demand": the intensive style calls for innovations which increase the productivity of land and/or animals, whereas the extensive style will primarily demand innovations which increase the productivity of labour. Furthermore, they expect "intensive" farmers to be more active in the "auto-production" of innovations, whereas their opposite will rely more on externally developed innovations. These latter implications of the incorporationist view are the most interesting in this respect, since they touch upon causal elements with the process of technical change. Moreover, this view explicitly embroiders on the popular notion of the "socialization" of agricultural research by placing it in the framework of an agricultural system; if anything can be concluded from a review of (agricultural) economic literature, it must be that technical change involves interactive movements between agencies of different origins (e.g., diverging economic sectors). As Bolhuis and Van der Ploeg rightly suggest, this process is essentially an asymmetrical one.

3.3.3.2 The agronomic imperative

In the view of the agronomist C.T. de Wit (1981;1987) the actually attained level of physical productivity is determined by (the state of knowledge concerning) agronomic principles and conditions, rather than by economic factors. Although this argument has not been elaborated sufficiently by De Wit et al, its influence on Dutch discussions about this subject is impressive. We will therefore briefly review this "agronomic imperative".

The standard illustration that goes with it, shows the historical pattern of wheat yields in US-, NL- and UK-agriculture in the 20th century; after the Second World War we can observe a marked yield growth (see figure 3.13).

Instead of relating this pattern to structural developments within agriculture, as De Hoogh did, De Wit asserts that developments within agricutural research constitute the principal drive behind this rupture:

> *"Because of the bad habit of expressing yield increases solely in terms of percentages, it has escaped people's notice that the magnitude of the yearly yield increases is independent of circumstances to such an extent. It is not only independent of the level of yields, of the soil and the climate, but also of social and economic relations. A satisfactory explanation for both the magnitude and constancy of the absolute yield increases does not seem to be available, but*

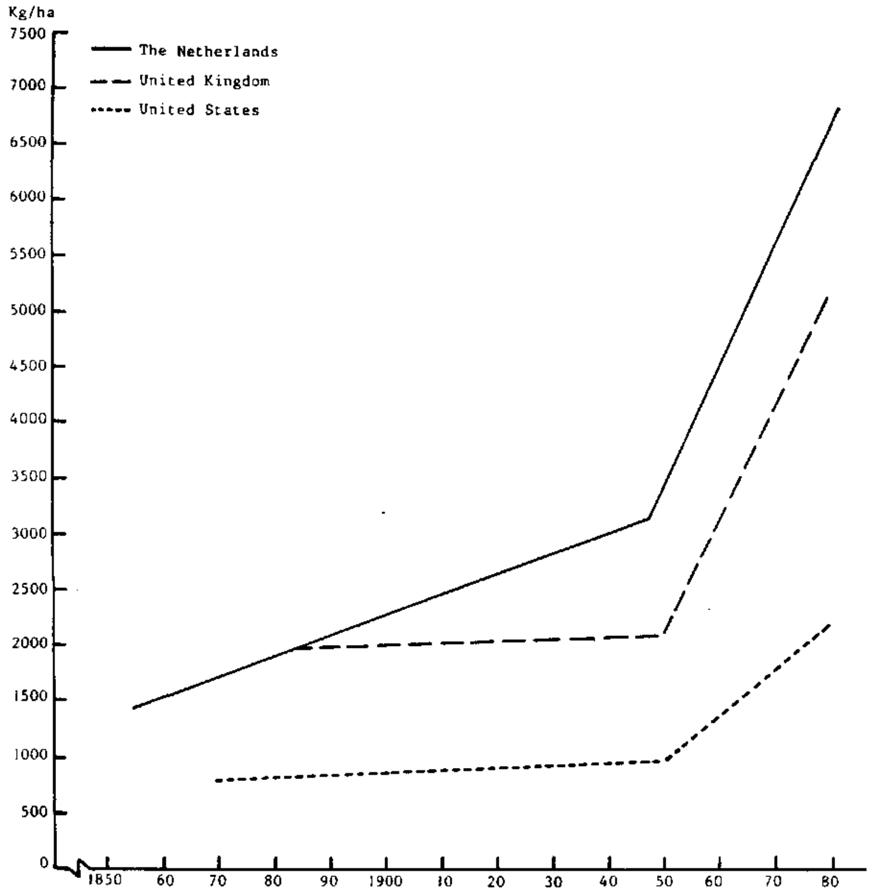

Figure 3.13 Wheat yields, US, UK and The Netherlands, 1850-1980
Sources: De Wit (1981).
Figures for The Netherlands based on Landbouwcijfers (CBS/LEI, The Hague), several volumes.

> *the phenomenon does indicate that a steady yield increase is the innovation par excellence in agriculture (..) .. much agronomic research persistently searches for new ways to increase yields and does not let itself be distracted by changing economic relations."*
> (De Wit, 1981:257; my translation, HR)

We could restate this argument by saying that agronomic research is primarily directed towards finding new or higher physical optima of input and output combinations the "average" farmer can eventually orient his production levels on. Of course this involves costs (purchased inputs), but the crucial argument of the agronomic imperative seems to be that (a) increased demand for these inputs will result in them being supplied cheaper 1), and (b) that substantial efficiency gains can be captured when moving towards higher optima 2).

Like the incorporationist view, the agronomic view in fact attributes great influence to technology supplying institutes and firms; economics do matter, but the most relevant feature - according to these views - seems to be that technology creates the contours within which economic variables exert their influence, rather than the orher way around. The incorporationalist view goes a bit further by arguing that the supply of technology is part of a prescribing complex, capable of manipulating economic conditions to a large extent.

3.4 Conclusions

The state of the art within agricultural economics with regard to the understanding of technological change is - generally speaking - not very impressive 3). Although many economists now acknowledge that technical change is one of the most influential features of (modern) agriculture, it still appears to be difficult to fully renounce the manna-from-heaven approach. In subsequent chapters we will pay more attention to many of the difficulties that may arise, or have arisen, in this respect.

When looking back upon the reviews in the same way as was done in chapter 2, one can notice a rather remarkable shift in the kind of problems which have had priority. This is most striking for the "farm problem": although this has been a hot issue in the 1950's and 1960's, in later years this was more or less treated - if it was treated at all - as a relic of the past. Technological change performed a very decisive element in past explanations of the farm problem. Later, it has become more an object of quantification, than an element of attempts to construct an over-all theory of how agricultural dynamics can best be understood. The main exception, of course, is the work of Hayami and Ruttan and their followers; but characteristically,

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1) That is, by means of efficiency increases in, e.g., the fertilizer industry, which in its turn is made possible by a larger scale of production.

2) Cf. de Veer (1986) ".. for many of the yield increasing inputs (..) further yield increases do not require higher inputs."

3) It must be noted that this review has concentrated on those economists that have indeed been occupied by the phenomenon of technical change. In that sense, it cannot be regarded as a review of 'the' agricultural economic literature.

their main arguments stem from the "Schultzian era", whereas the more recent activities of agricultural economists mainly serve as a "filling-in" of these arguments. Strictly speaking, there is of course, no problem whatsoever with this line of thought. But as will be argued in chapters 4 and 5, their is now need of a certain readjustment of both the priority list and the theoretical concepts and approaches of agricultural economic theory.

4. The generation of technical change in agriculture

4.1 Introduction

As we have seen, many authors stressed the endogenous character of technical change. That is, it is considered to be an economic affair, implying costs and benefits, and choices among alternatives. Moreover, certain economic agents come to the fore as producers of (new) technologies: research and development (R&D) institutes, universities, producers of means of production, et cetera 1).

In his search after a proper taxonomy of sectoral patterns of technical change, Pavitt (1984) classed agriculture - together with housing, private services and traditional manufacture - under the "supplier dominated" sector. For this sector it goes that "most innovations come from suppliers of equipment and materials, although in some cases large customers and government-financed research and extension services also make a contribution" (Ibidem:356). Its general trajectory is characterized by "cost-cutting" (as opposed to "product design" in the "specialized production intensive" sector) and the use of innovations is generally price sensitive (Ibidem:354). Thus, in the agricultural sector there is a rather sharp dividing line between technology producers and technology users, i.e., compared with science based industries such as electronics and chemicals.

As far as agriculture is concerned, it is a quite general belief that technical change is a socialized matter, meaning that public interventions and stimuli constitute the most influential forces in changing agriculture's technical options 2). Indeed, the relatively small scale of farm enterprises prohibits the development of an on-farm regime of R&D, capable of counteracting or at least responding to changing economic conditions. This

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1) For this reason, Kislev and Peterson (1981) stressed the necessity - from the analytical point of view - of separating technology-applying from technology-producing sectors. They therefore criticized the Hayami-Ruttan model, for its neglecting of 'internal and external' inducement mechanisms.

2) Cf. e.g., Hayami and Ruttan (1985:107): "The socialization of agriculural research or the predominance of public institutions in agricultural research, especially in biological sciences, can be considered a major institutional innovation designed to offset what would otherwise represent a serious distortion in the allocation of research resources". See also Schultz (1945), Heady (1949), Hadwiger (1982) and Evenson and Kislev (1975).

alone provides extensive governmental interference with logic and - historically - inevitability 1). Hayami and Ruttan (1985:106) made this quite clear:

> *"If agricultural research were left entirely to the private sector the result would be serious bias in the allocation of research resources. Resources would flow primarily to areas of mechanical technology that are adequately protected by patents and to areas of biological technology in which the results can be protected by trade secrets (such as the inbred lines used in the production of hybrid corn seed). Other areas, such as research on open-pollinated seed varieties, biological control of insects and pathogens, and improvements in farming practices and management, would be neglected."*

In so far as technical change in agriculture is formalized, it is, however, far from completely socialized. Blaming as well as praising only public efforts for its implications, both denote a denial of the crucial role private institutions play in this respect. Thus, according to figures from Ruttan, private research in the U.S.A. in 1979 probably accounted for about 65% of all research that was directed towards agriculture, a share that has been rising steadily over time 2).

The effect of agricultural R&D upon productive performance is, so it appears, very hard to quantify. One of the rare attempts to do so stems from Lu and Quance (1979), but their computations concern only public research. Lu and Quance found that a single 1% increase in public expenditure for research and extension in US agriculture (in the seventies) would result in a 0,037% increase of total factor productivity over thirteen years (Ibidem:5). Obviously, these calculations can only be indicative, as is the case with the more popular cost/benefit estimates. The latter calculations, expressing the economic efficiency of R&D

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1) This is not to suggest, however, that farmers have become pure 'technology takers'. Evenson, for example, estimated that 'perhaps one-fourth of the time of a typical family farmer is devoted to searching, screening, and experimentation with new technology" (Evenson, 1982:237). Especially with regard to the production of biological technology (like breed improvements) the image of the technology taker is quite exaggerated (Ibidem:241). See also Biggs and Clay (1981:326), according to whom".. the greater part of the agricultural technology in use in the Third World, and therefore in use throughout the world, is accounted for by informal innovation".

2) Ruttan (1982a:23). In 1965 the share of private research was 55%. See also Hayami and Ruttan (1985:250-251).

expenditures, have almost never resulted in figures below 10% 1). Logically, this raised the question whether (public) investments in research, development, extension and education should not be increased. Subsequently, much of the debates among agricultural economists on this subject as a matter of fact centered around the correctness of these calculations, less on developments within "socialized" R&D, and even far less on "private" R&D 2).

These kinds of calculations, however, pass over a more obvious problem, which is the question as to why researchers - in private or in public institutions - do what they do. For it cannot be asserted that the contents of their activities are to be deduced from their (productive) effectiveness or efficiency performance. Research involves choices between alternatives, and thus represents a process of selection. Whether the prevailing criteria concern budgetary matters, matters of technology (e.g., opting for the most promising research line from a scientific point of view), or matters of economic interests, is of a second order. The first thing to determine is this selective element within research. As we have seen earlier, the Hayami and Ruttan approach to this problem is quite uncomplicated; in their view the main selection criterium is derived from the passing on by farmers or their organisations of market signals (changing relative factor scarcities) to technology-producing institutions. Although Hayami and Ruttan must be credited for the fact that they have attempted to incorporate the initiation of technical change in their model, this approach leaves much to be desired. Holland (1980), for example, argued that "the issue of who is allowed to define the important problems" (Ibidem:973) is far more decisive. And his subsequent view on this issue is that:

> *"Agribusiness (..) and the larger farmer's interest are the most important here. Since the research perspectives of each of these groups are dominated by the large concentrations of capital represented, the problems defined are those of the*

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1) For an informative summary of these calculations, see Evenson and Kislev (1975), and Fox (1987). A major problem is that failed research projects are often left out of the picture. Price (1983) argues that - generally - too many cost categories are not accounted for, and that the distribution of costs and benefits between social groups is often neglected.

2) Although it must be noted that private expenditures are even more difficult to retrieve.

large agribusiness firms and the largest farmers."
(Holland, 1980:973) 1)

Thus, research is not just an at random (applied) scientific act of puzzling, but part and parcel of its socio-economic environment.

Since it cannot be expected that there is an unambiguous relationship between "who defines the problems" and "how the problems are solved", the next element of the selection process in R&D is the type of research that is conducted. The literature on this subject is quite unanimous about a crucial difference between public and private research in this respect, i.e., that because of the difficulties to capture the gains from new technologies, private enterprises conduct research in fields that a) give opportunities to patenting or other forms of protection, and b) for which there is or is thought to be a substantial demand, whereas public research, almost by nature, is far less susceptible to both these conditions. Although, as we have already seen in paragraph 3.1.1, this has given rise to the practice that research for mechanical innovations is predominantly conducted by private firms, and research for biological innovations by public institutes, underneath this general image things appear to be far more complicated. An illustrative example is offered by hybrid corn research in the US after World War II. Evenson (1982) 2) reports that the first research activities in this field were undertaken by public agencies. After a few results were achieved, private firms began to show interest, jumped on the bandwagon and soon came with a new variety. In the subsequent competition between experiment stations and these private firms, the former soon began to lose ground, and "by the 1950s or 1960s, almost all of the final hybrid lines used to produce (hybrids) were products of the private sector" (Evenson, 1982:274). In addition, Evenson adds, this trend has reversed completely in recent years.

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1) Ruttan himself, for that matter, would be the last to deny this, as he once stated very clearly that Cochrane's product treadmill "limits the economic motivation for support of agricultural research to a relatively small population of early adopters of new technology. The early adopters also tend to be the most influential and politically articulate farmers" (Ruttan, 1982:257). See also Busch (1984:303), who adds that "groups such as consumers and farm workers have minimal impact on the information of research agendas as they remain largely unrecognized and have great difficulty in establishing access to the system".

2) Which in turn is based on an article by Griliches ("Research costs and social returns: hybrid corn and related innovation", Journal of Political Economy, 66(1958)).

This leaves us with the picture of a variety of research institutions, consisting of very diverging elements each with their own interests, decision criteria, organizational characteristics and linkages with primary agriculture. Since this is not the place to embroider on this complexity at great length, we will confine ourselves to the two most distinct bodies of "researchers": public agencies and private firms.

4.2 The role of government institutions

Why have governments in most industrialized countries embedded themselves so heavily in agriculture and less in other sectors of the economy? What makes agriculture so special in this respect? First of all, it should be noted that governmental interventions in agriculture have developed over time. That is to say, only from the beginning of the 19th century did states start to formulate policies explicitly directed towards the agricultural sector 1). At first, the exact shape of this policy differed greatly from country to country, but in the course of the 20th century, governmental interventions in most western economies basically consisted of the following three elements:

- a market policy, meaning some kind of regulation of supply and trade by means of foreign trade measures and price support;
- a structure policy, aimed at improving both the technical and economic infrastructure of farms;
- a modernization policy, consisting mainly of research, development, education and extension.

Although one is easily tempted to connect the third element with the production and spread of innovations, both market and structure policy play a significant role in the contribution of states to technical change in agriculture. Thus, the mere fact of a certain degree of price stabilization is thought to be a crucial condition for maintaining a high level of productivity growth, since it provides investment plans with some certainty 2). In fact, this policy of price stability represents a very crucial choice as to how productivity growth in agriculture can best be achieved, as well as a departure from "pure" neoclassical premises: signals from the market (relative price movements) are dampened and this - as the neoclassical would argue - will slow down or obstruct adjustments in the structure of agriculture; ad-

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1) See Koning (1986 a and b), and Petit (1985).

2) Cf. Van den Noort (1966:791) and Cochrane and Ryan (1976:376). Obviously, some authors claim the relatively high level of these prices to be responsible, rather than their stability. See, for example, Roberts, et al. (1985).

justments which are necessary to provide innovators with the maximum of innovating rents. Pure neoclassicals will look upon many structure policies, which are among other reasons designed to cope with this criticism, as an admission of weakness. (See also our treatment of Cochrane's two variants of his treadmill theory in paragraph 3.3.2.1.)

Consequently, when considering the influence of state intervention on technical change in agriculture, it is insufficient to focus exclusively on the role played by state sponsored research and related activities such as extension services. However, when only this research and related activities are concerned, it appears to be quite difficult to get a grip on the decision processes involved. For it may be true that the state has hardly any or no choice whether to invest in agricultural research or not, there still remains a great array of choices as to the kind of problems that are to be tackled by research and the kind of research this involves. To understand this, it is necessary to look beyond the scale argument mentioned at the beginning of this chapter and return to the diverging roles that technical change can play in production. Thus, a first major characteristic of technical change is that it allows for (easier) substitution between factors of production: in western agriculture this has called for labour- and land-saving technologies. A second characteristic is represented by the sheer output-increasing effect of technical change: again, this has predominantly been of a labour- and land-augmenting type. Both these characteristics have been the subject of publicly sponsored agricultural research, although there may have been an evolution in priorities in this respect. For example, it can be expected that in times of full or nearly full employment, research efforts in agriculture will be primarily directed towards labour-saving technologies, whereas in the reverse case, more priority will be given to labour- and land-augmenting technologies. One of Hadwiger's conclusion of his study the politics of agricultural research institutions is typical in this respect:

> *"Inside this subsystem there has been agreement on some research goals, such as reducing human labor in agriculture and, in general, increasing agricultural productivity per unit of output (..), while other potential research goals have been explicitly discouraged, among them those of preserving the physical environment, encouraging rural community development, and improving consumer nutrition."*
> (Hadwiger, 1982:198)

Unfortunately, agricultural economic literature offers very little on this subject, which actually deals with the evolutionary concepts of paradigms, trajectories, selection and exclusion: although it is often recognized that public expenditures have been responsible for a large part of the often tremendous productivity increases, its inner dynamics seem to look very much like technical change itself: a black box. To make things worse, the dynamics of private research seems a field just as unexplored.

4.3 The role of private institutions

In introductory textbooks on agricultural economics, the collective of farm-firms is shown to be surrounded by an "agribusiness complex", consisting of both private and public institutions with agricultural activities. In popular language this agribusiness complex often is incorrectly restricted to agricultural industries and ditto trade firms, thereby leaving out industries to which agriculture is no more than a subsidiary branch. However this may be, private non-farm intervention with primary agriculture certainly matches its public counterpart as far as its "technology-pushing" activities are concerned: private firms invest considerably in research and development, and in the speeding up of the adoption of innovations.

An illustrative example of the number and the diversity of (private) firms that can be engaged in the production of new technologies is given by Roobeek (1987:146). Next to micro-electronics and new materials, she considers biotechnology as a "key technology" within society at large. A key technology is characterized as being (a) highly influential with regards to the social economic and political structure of present-day economies, and (b) developed and stimulated by numerous divergent (sub)sectors within the economy. (See also parapgraph 2.4.5) In Roobeek's view, the production of biotechnology takes place within a "web" 1) (Figure 4.1).

Figure 4.1 makes clear that the development of biotechnology is not only directed towards application in primary agriculture. That is to say, the fact that agricultural R&D - for a substantial part - takes place outside primary agriculture implies at the same time that the criteria which are laid down with regard to the supply of new techniques to primary agriculture enter a much broader oriented decision making process. For many technology supplying firms will first consider whether to invest in agricultural R&D before deciding what kind of agricultural R&D is most profitable. Consequently, the more firms which (used to) conduct agricultural R&D move away from this working field, the more non-agricultural economic variables affect their decision-making.

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1) Cf. Clark (1985:62 a.f.) who could call this biotechnology web an example of a "science system", consisting of "those institutions and social structures whose activities consist mainly in the discovery, articulation and propagation of scientific and technological knowledge".

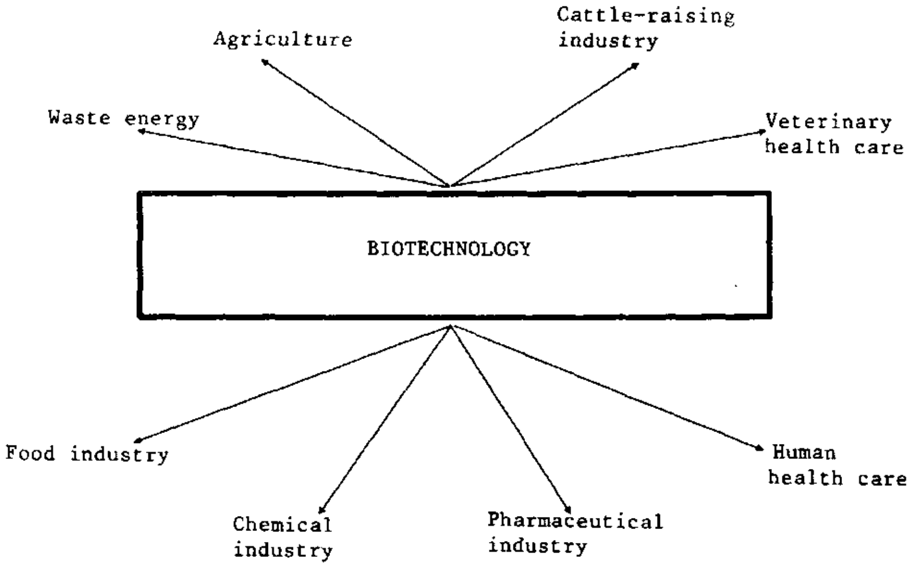

Figure 4.1 A simplified biotechnology web
Source: Roobeek (1987:142)
N.B. The arrows represent "having interests in" and/or "is engaged in research and development".

In addition to these specific conditions that surround the process of selection within private firms, an even more distinguishing feature must be noted. This concerns what has become known as the "exclusion effect" 1). In general, as we have seen in paragraph 2.4.5.2, this term refers to an implicit or explicit short-sightedness of researchers with regard to alternative directions of research. In that sense, there will be no difference in the ways in which public R&D is undertaken. However, in the case of private R&D this exclusion effect can more or less be formalized through patenting; so to say the legal expression of exclusion.

When reviewing agricultural economic literature, as said earlier, one can notice the strikingly meagre attention that is given to the subjects dealt with above. Again, the research agenda of agricultural economist needs substantial completion.

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1) Cf. Dosi (1984:15).

5. Technical change and prices in agriculture

"The significant thing in (the) expected response of agricultural production to various levels of relative prices is the propensity of supply to increase in spite of falling prices - a rough measure of the strength of the forces that are at work reshaping the supply."
(Schultz, 1945:81)

5.1 Introduction

Thus far, we have merely reviewed the perceptions of economists and their agricultural colleagues on the phenomenon of technical change. As stated in chapter 1, we originally took interest in the relationship between technical change and prices. In this chapter we will try to recollect the foregoing views by concentrating ourselves on this matter. From this recapitulation, we will thereupon try to formulate a general framework for treating this relationship.

What is meant by "prices"? Clearly, product prices alone are all but the only determinants of technical change. Even when confining ourselves to the role of prices, we have to acknowledge that relative product prices matter (e.g.,price of cattle relative to prices of grains), and prices of factors and means of production as well. As a matter of fact, the statement of many authors that expected profits serve as one of the most important determinants of both the rate and direction of technical change, clearly indicates that it is the whole constellation of relevant prices that needs to be considered, rather than just one of its categories.

Furthermore, we can expect the movement of prices to be of significant influence, irrespective of its category. For we may safely assume that farmers will react differently in the case of heavily fluctuating prices in comparison with a situation of stable prices. Boussard, for example, stated:

".. a policy of price stabilization on a previous average level will, in a longer run, result ceteris paribus in a sharp increase of production. This is a fact that is too of-

ten forgotten. Then, the price elasticity of supply is not necessarily positive."
(Ibidem:40) 1)

Thus, in this chapter we will deal with prices in general, their trends, and as much as possible with relative prices as well.

5.2 The influential role of prices relative to other factors

In order to assess the role of prices in the process of technical change, we must first take stock of other influential factors. We could do this by producing a list of supposed determinants, but apart from its length this would be a rather tedious affair. Instead we will employ two different ap-proaches. First we will present a scheme of supply and demand of new techniques c.q. technologies, reflecting the interrelated and dynamic character of the process of technical change. From this general scheme we will try to deduct the relative importance of prices. The second approach consists of a review of the economists' opinions on this subject.

5.2.1 The causal role of prices I (scheme)

More or less inspired by the scheme constructed by de Janvry (see 3.3.2) and based on fragments from relevant literature, we can build ourselves a stylized image of the determinants of and the interrelatedness between supply and demand of new techniques (figure 5.1) 2).

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1) Cf. Farrell and Runge (1983:1172) who found that the agricultural chapter of the US New Deal policy engendered ".. a climate of comparative security which promoted more rapid rates of technological change in agriculture". Opposed to this is G.L. Johnson's view (1972:175) that price support programs (a) "extend the economic life of investments in old techniques in existence when the supports were inaugurated", (b) "stimulate investments in technologies available at the inception of a price support program, thereby making it unprofitable to invest in the more advanced technologies becoming available at later dates in the programs", and (c) that "high initial but declining price supports (..) produce even more obsolete technology at later stages in the program".

2) De Janvry and Dethier (1985:10) present a somewhat revised scheme of the one portrayed in paragraph 3.3.2. A similar scheme has been developed by Fox (1987:458) in his efforts to assess the costs and benefits of agricultural research. Coombs et al. (1987:11) constructed a analogous model of determinants of innovative activities, although this model is not restricted to agriculture.

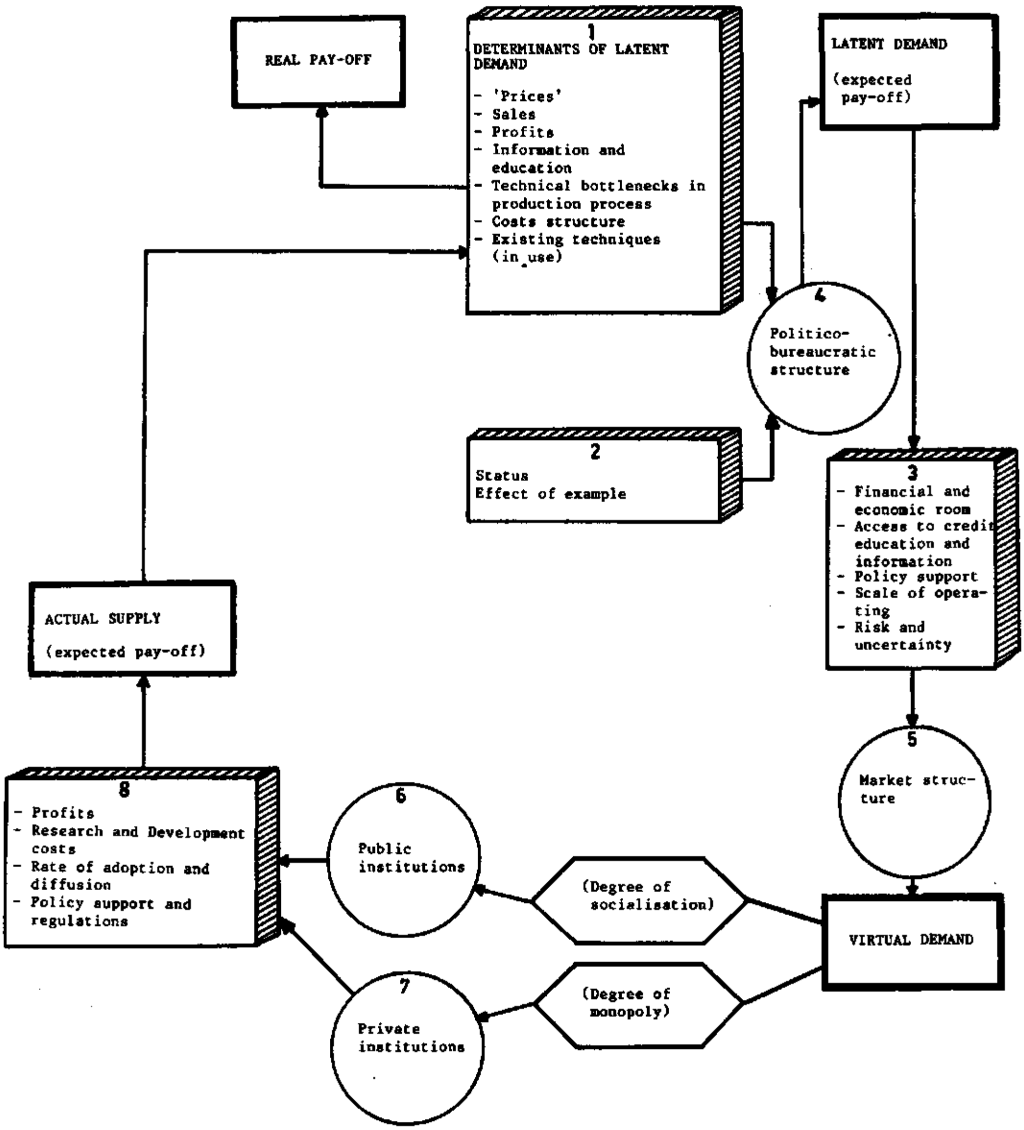

Figure 5.1 Scheme of supply and demand of new technologies

The first two blocks of figure 5.1 (number 1 and 2) represent various kinds of technical, sociological and economical bottlenecks and ditto incentives at the farm-level. Together they constitute the latent demand for new technologies. For example, farmers who have been trained in the use of computers, will be more inclined to search for useful applications than farmers to whom computers are merely a distant phenomenon. Or, when profits of red cauliflower are expected to be high, farmers will be more inclined to get informed on the technique of producing this new product. Apart from constituting latent demand, the determinants mentioned in the first block are also crucial to the ultimate benefits of adopting new technologies. Computers only pay off, when chosen properly and used properly. Red cauliflower only pays off, when its cost of production and economic yields indeed correspond to expectations, and so on.

The third block represents, once more at the farm-level, the factors which make latent demand become actual demand: at this stage, farmers will determine whether they are able to meet their aspirations or not: is their farm large enough for the desired new machinery, can they afford the investment, do they have the appropriate knowledge, what support can they expect from public policy, if some improvements of technology at hand would not suffice, etc. Again, and now we are dealing with the meso-level, these factors will be influenced by their outcome, that is, the actual supply of new technologies. For only then it will become clear whether they have made the right choices, i.e., whether their needs can be fulfilled, and whether the technology supplied corresponds with their expectations. In this respect, "waiting" will often be an important phenomenon: when new techniques become rapidly available - and with that their subsequent improvements - it can be very rational to wait until things have settled down and the risks are both known and more or less controlled (Farrell and Runge, 1983:1170). In addition, these new techniques may be of interest to only a limited number of potential buyers, since both latent and actual demand will still represent a wide variety of desires. Take for example the demand for farm computers, which in theory may consist of a demand for numerous systems and applications by - moreover - a segment of the farmers population. It is very unlikely that actual supply will properly meet all these demands. Consequently, the "transition" from latent to actual demand may become somewhat frustrated: to some farmers, the technique actually supplied didn't turn out to be the technique they wanted or expected, to others the technique developed suited their demands, but appeared to involve too many (unexpected) risks.

To proceed with the sequence of the scheme; apart from the on-farm production of new techniques (which will often be mere improvements of existing techniques), there are two ways in which latent demand can be translated into actual demand. The first is called the "politico-bureaucratic structure", i.e., that farmers will call upon public agencies to supply the demanded technique. This "request" will be decided upon, mainly in accordance with reigning rules and criterions within these agencies. The second way is through the "market": farmers will urge farm-related private agencies to produce the desired technique, for which they will be paid in return. These two ways of transforming latent demand into virtual demand can be taken together under the heading of the "information structure", for in both public and private institutions the availability and specificity of information is crucial with respect to the innovative decisions made by farmers.

By definition, the degree of socialization of agricultural research determines the value distribution between private and public institutions. And whereas the rate of imitation, i.e. the adoption of innovations from other sectors, is likely to be high in agriculture, it can be hypothesized that the degree of monopoly influences the amount and type of R&D that is undertaken by private institutions. Thus, for example, the higher the degree of monopoly, the more selective and exclusive R&D will be 1). For (actual) demand to become supply, both public and private agencies will have to conduct their own calculations of what it is worth to undertake the generation and dissemination of a new technology. In the eighth block some relevant criterions are summarized, although we should note that, as we have seen from chapter 4, these criterions will be more clear-cut in private institutions, than in public institutions 2). Apart from this, whether the institutes are private or public, in both cases an analysis will be undertaken of the costs and benefits involved in the production of a new technology. In this analysis, expected profits, expected rates of adoption and diffusion, calculated development costs, policy regulations, and future prices will undoubtedly play a crucial role. Furthermore, their decision will also be heavily influenced by what we have called the state of science and engineering, i.e., whether the required technology fits the reigning technological paradigm and trajectories; in other words, whether the problems posed - in the form of the technology request - can be dealt with *within current research lines*, or if they require *breakthroughs* in this respect.

The result of these calculations may ultimately be the actual supply of new technologies: in that case a positive pay-off

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1) See, for example, in the case of biotechnology: Goodman et al. (1987) and Roobeek (1987;1988).

2) See for example Hayami and Ruttan, who stated: "It is useful to think of a supply schedule of institutional innovation that is determined by the marginal cost schedule facing political entrepreneurs as they attempt to design new institutions and resolve the conflicts among various vested interest groups (or suppression of opposition when necessary)" (Ibidem, 1985:107).

is expected. Subsequently, the pay-off becomes reality when the new supply of technologies is in accordance with both the criterions and conditions of demand (blocks 1 and 2).

Assuming this scheme represents reality sufficiently, a few conclusions may be drawn:

1. To begin with, there are some sociological factors at work, which are merely indirectly connected with economic variables. The introduction of new technologies does not only bring about changes in the sphere of production, it often calls for mental or intellectual and cultural changes as well. This not only accounts for "status" and "example", but also belongs to the realm of what we have entitled "technical bottlenecks". From the view point of the entrepreneur, one of these bottlenecks may well be any (expected) decline in control over hired labour-power (Price, 1983).
2. Both the rate and the direction of technical change are, to a certain extent, (pre-)determined by the existing stock of techniques. Much will depend on the ease at which existing techniques can be exchanged for by the new techniques, that is, the investment and profitability involved in the combined act of selling the old technique and purchasing the new one.
3. Purely production-technical considerations may altogether form the primary motive for the search for new techniques. For example, labour-easing techniques may be demanded without primary concern for their economic advantages, but rather because of the irksomness of certain activities.
4. For demand to become actual supply, decisions within both public and private institutions are crucial and it is essential to regard these decisions as being quite distinct from the kinds that were made in the phase of demand. According to the Induced Institutional Innovation theory, institutions will try to make available "new technical possibilities and new inputs which would enable farmers to profitably substitute the increasingly abundant factors for increasingly scarce factors" (Hayami and Ruttan, 1985:88), thus responding to changing relative factor scarcities. But in reality they obviously also have to take into account their own economic and political criteria.
5. Every transition within the scheme involves some sort of *selection* and *exclusion* based on differential criteria. The previous conclusion actually is an example as far as the transition from virtual demand to actual supply is concerned, but in earlier stages too, at the farm level for example, selection takes place on the basis of criteria that might well differ from one farmer to another.
6. The role of prices is limited in that they represent one out of a broad spectrum of influential factors. Moreover, prices enter the scheme at different places and in different shapes. Consequently, block 1 represents both product prices

and input prices, block 2 emphasizes financial prices and price expectations, block 8 refers to prices that reign on a completely different market, et cetera.

Comment

Yet, the foregoing scheme has some serious drawbacks. To begin with, the sequence chosen (from demand to supply) is quite artificial, if not highly idealistic 1). Thus, we can think of new technologies being supplied with only vague or little knowledge about the state of demand. We could also have started our scheme by presenting the producers of new technologies looking for markets on which they can sell their products or the products they aim to produce. In that case, technology suppliers would have been the active agents rather than farmers. In other words, the latter course of action would suggest technology suppliers to be the engine propelling technical change, rather than farmers themselves; technology would then be pushed rather than asked for. The point to be made here is that neither of the two sequences is preponderant, for in reality reciprocity will reign, rather than a one-way traffic.

Secondly, we have depicted the farm sector as an aggregate, whereas its structure in terms of farm size, solvability and profitability - in general terms: micro-economic performance - is highly heterogeneous. Thus, virtual demand will undoubtedly turn out to be a selective demand, with some farmers seeking for a certain new technology, others resisting it, and still others not seeking any new technology at all.

Thirdly, the determinants of latent demand described in the first block do not necessarily apply exclusively to a demand for new techniques, but may as well constitute the incentives for solving problems in another way, e.g., by a further intensification of the production, by increasing the scale, by adjusting existing techniques, or - in general - by economizing without the use of new techniques.

Finally, during the process of technical change, all blocks and all elements contained in them, can undergo more or less fundamental changes. For example, new institutions can be created, and older ones may vanish; government restrictions may replace by government support, et cetera.

This being said, it remains of interest to take a closer look at the views of agricultural economists on the connection between prices and technological change, a subject to which we will now return.

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1) Cf. Bieri et al. (1972:802): ".. in our model farmers themselves generally do not design and send in orders for tractors and seeds not yet in existence. They are not only price-takers but, on the whole, als technology-takers!".

5.2.2 The causal role of prices II (views)

As we have seen in the second chapter, prices (of various kinds) are a major feature in the agricultural economists' explanation of technical change. We will now deal with this part of their views more explicitly, by sub-dividing the subject matter into two categories:

1. The price-responsiveness of output
2. The price-responsiveness of technical change

Obviously, the way in which these two questions will be dealt with, will be only slightly more than a neat recapitulation of our former treatments.

5.2.2.1 Prices and output: supply analysis

"The aggregate supply of farm products for the nation changes little, if at all, with changes in the farm price level." Thus stated Cochrane in 1958 (Ibidem:45). The French economist Boussard (1985:40) opposed this opinion by stating that "(product;HR) prices can, under no circumstances, be considered as having no impact on production". More or less in between stands the opinion of D.G. Johnson (1950):

> *"Given technological change, falling real farm prices need not produce a decline in total output in agriculture. The autonomous shift in the production function may increase the marginal physical productivity of each of the resources sufficiently to counteract the decline in resource use."* (Ibidem:264)

Clearly, supply analysis has always been a major source of confusion and dispute among agricultural economists. There has never been, however, any question about the "supply-shifting" effect of technical change in agriculture, although it is acknowledged that a) technical change is not the only "supplyshifter", and b) movements along the curve also need to be considered. Consequently, it appears that, in our search for the influence of prices upon technical change, we are allowed to restate our problem first in terms of general supply analysis. As will be argued, this procedure will shed only a dim light on our problem. The main reason can be found in the interrelatedness of all relevant supply determinants, and in the dynamic character of all production relationships. In other words, when none or few determinants are completely independent, and when their economic impact is changing continuously, supply analysis inevitably becomes an, quoting Hill and Ingersent (1977), "extremely hazardous" approach. This is not to say that supply analysis has no meaning or sense in this respect; it does provide us with basic information on supply relations. In this paragraph we will try to clarify both the virtues and shortcomings of supply analysis. This will be done mainly by briefly reviewing parts of the extensive body of literature on this subject, especially limited to the price-elasticity of supply.

Supply determinants

The quantity of agricultural products that are supplied to the market is determined by a great number of factors. Thus, the supply function for a specific product can be formalized as follows:

$$Q = f(T, Pp, P1...n, I1...m, N, R, S),$$

where T stands for technical conditions of production, Pp for the price of the product concerned, P(1...n) for the prices of competing products, I(1...m) for the prices of inputs, N for the number of farms, while R and S stand for rationality and structure. The ceteris paribus variant often comes down to:

$$Q = f(Pp, P1...n)$$

Stated this way, the supply function embodies several complications. To start with, the level of aggregation has great influence upon the empirical results. A farm sector consisting of 100 farm-firms may well come up with a large number of different elasticities: each farm-firm is different from the other in terms of its technical characteristics, scale of operation, degree of specialization, etc., all influencing the parameters of the function to such an extent that it is doubtful wether this can be accounted for by a representative general structure. To give an example: Wilcox, Cochrane and Herdt (1974) made a distinction between a) low production family farms, b) commercial family farms, and c) large-scale commercial farms. The price elasticity of supply was found to be "completely in-elastic" for the first, "highly inelastic" for the second, and "not perfectly inelastic" for the third. This means that, for example at the national economic level, the price elasticity may change exclusively because of a changing structure, a point Boussard (1985:39) emphasized.

What prices?

Another problem is Pp itself: do farmers react to past (experienced) prices (Nerlove, 1958), to actual or current prices, or to future prices 1)? And, should it be the off-farm price, or, as Van den Noort (1965) suggested, "net-prices"(the off-farm

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1) That is, price expectations based upon expected changes in price policy, market movements, and so forth.

price minus prices of inputs)? Obviously, the reaction to price changes may take considerable time, reason why short term elasticities are often smaller than longer term ones. But economists still have great difficulties explaining the time-consuming character of the adjustment process.

'Handbook economics' tells us that any diversion from the optimum - defined in terms of the equation between marginal costs and marginal benefits - will call for adjustments. However, as has been put forward by De Hoogh, this marginal approach may not apply to agriculture:

> *"Whereas private labour and private capital, united in the entrepreneur as a person, are given quantities, the total reward for the complex of these factors of production, will be the decisive farmer's criterion as to whether or not he will change or quit this complex of factors of production."* (Ibidem, 1967:9; my translation,HR)

Translated in terms of our problem, this would mean that rather than marginal, average costs and benefits constitute the crucial criterion for investment plans.

Rising versus declining prices

A related complication concerns the movement of prices; we already discussed the difference in reaction to sudden price changes as opposed to gradual changes. Several studies have also suggested that the reaction to price changes is not neutral with regard to the direction of these changes; that is, farmers may react differently to a X% price decrease than to an equal price increase. One of the first studies of the effect on output of rising versus declining prices stems from Galbraith and Black (1938) 1) in their analysis of supply reactions during the years of depression. In later years many authors extended the analysis for periods of prosperity, c.q. full employment 2). Their general contention confirms the notion that it is easier to increase output by means of higher prices than to reduce output (through lower prices). Cochrane's view, for example, as summarized by Tomek and Robinson, was expressed as follows:

> *"During periods of rising prices farmers have both the incentive and the necessary capital (out of retained earnings) to invest in output-increasing technology, but the process*

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1) See G.L. Johnson in Heady et al. (1958:74-76). In a lengthy footnote, Johnson reviews the main contributions to this debate.

2) Cf. D.G. Johnson (1950), Schultz (1953, 1956), Heady (1958), Cochrane (1958) and Hathaway (1963).

is not reversible. Once the new technology is adopted, it will not be abandoned. In periods of falling prices the output of the typical farm-firm (and hence the total output) does not decline because of the lack of alternative uses for some factors of production, induced changes in the prices of factors with inelastic supply schedules, and a general commitment on the part of many of those in agriculture to continue farming despite low returns."
(Tomek and Robinson, 1977:359)

Tweeten and Quance (1969:20) also calculated higher price elasticities of supply during periods of rising prices than during periods of declining prices. The argument is put forward in the same vein by Simantov (1974), who considered the output-steering capacity of price policy to be limited to situations of insufficient supply; in that case higher prices would produce some effect, whereas - in his opinion - oversupply could hardly be reduced by lowering prices. This issue is also known as the "irreversibility-" problem, and is depicted in figure 5.2. Here, when price increases from P1 to P2, output rises from Q1 to Q2. A subsequent decline from P2 to P1 causes output to decline to Q3 instead of to Q1 again.

In fact, we can distinguish three different price-output relations in this figure: an elastic supply when prices rise; when prices go downward, supply may be inelastic up to a certain level (P1), after which it becomes elastic again.

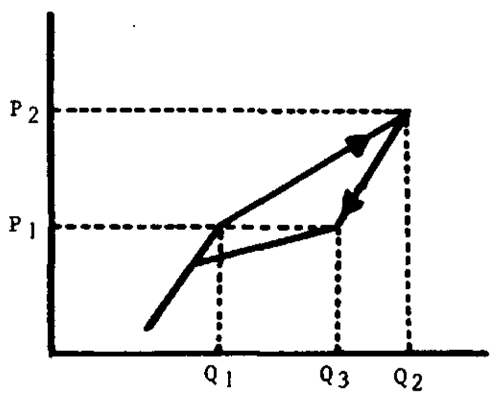

Figure 5.2 The effect of rising versus declining prices
Source: Edwards (1959)

According to several economists, this kind of supply response is to be explained by the phenomenon of "fixity" of resources, or more precisely, the becoming fixed of resources at certain levels of productive activity 1). Edwards (1959:755) formulated this as follows:

> *".. for small product price changes, most assets subject to fixity will remain fixed at existing levels and one would expect an inelastic price response. For larger price changes, additional resources become worth changing and the response becomes more elastic."*

This explanation has been widely discussed ever since it was first mentioned. And although the specificity of the fixity phenomenon for primary agriculture as opposed to other economic sectors can still be questioned, there now is a consensus among agricultural economists about its relevance to supply analysis. In short, the theory of fixed assets states that investment decisions are influenced by a divergence between the costs of acquiring factors and means of production, and the benefits of selling already acquired factors and means of production; a divergence which is not caused by wastage, but rather by both sectoral and micro-economic incompatibilities with regard to use. In G.L. Johnson's terms (1963): the salvage value of factor X or asset Y may well be beyond its acquisition costs. This is most obviously the case for assets like drainage systems, fruit trees, and barns, which are not only quite specific to agriculture, but also to the individual farm-firm, a specificity which might even cause the salvage value to be negative (because of the costs of removal). In his brief review of the fixed asset theory, Hathaway has systematically examined its applicability to various kinds of inputs at both the micro- and the meso-level. He concludes that,

> *"...over a wide range of economic conditions asset fixity is important for the industry, in that resources once committed to farming tend to remain in the industry. Thus, over a wide range of product prices the aggregate supply function for farm products appears to be completely inelastic or, in extreme cases, backward bending. (..) Within agriculture we find that resources in the industry tend to be less fixed on individual farms and much less so in the production of individual commodities."*
> (Ibidem, 1963:125; my emphasis, HR)

He adds to this conclusion that the extent and duration of asset fixity are closely related to "economic events outside of

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1) G.L. Johnson defined an asset as fixed "so long as its marginal productivity in its present use neither justifies acquisition of more of it nor its disposition" (In: Heady et al., 1958:78).

agriculture". For example, in times of full employment, the acquisition costs of labour will tend to rise, whereas its salvage value will be lowered in a situation of substantial unemployment. Thus, it seems that any theory, aimed at explaining the price-supply relation in agriculture has to include interactional features vis-à-vis the economy at large. This also means that we cannot speak of "the" price-supply relation. Indeed, the induced innovation theory of Hayami and Ruttan (1985) shows the vast impact of changing factor ratios upon the conditions and structure of agricultural supply; Heady (1949;1958) and, in a way, Cochrane (1958;1965) have shown the influence of general political economic forces upon agricultural supply; in the fertilizer case of Griliches (1957) we can find an assertion of the influence of developments within agriculture-related industries, and so forth.

Price elasticity of supply revisited

As we have seen, the most commonly used analytical instrument of (agricultural) economic theory is the price elasticity of supply. We already shortly discussed its theoretical status, and it will not come as a surprise that its everyday use offers far from satisfying results. A number of attempts to quantify the price-output relationship can be put forward to illustrate this.

For example, four recent studies on the long run aggregate supply elasticity for agriculture in the EC indicate it to range from 0.3 to 1.0 1). This divergence of outcomes is rather startling, especially because of the fact that the long term elasticity figure plays such an important role in (projection) models. The authors from whom this summary is borrowed, conclude from their computations that the medium figure (based on real prices) is approximately 0.7; the happy medium. The BAE-report also presents a simulation model which observes the supply response to different product price levels in the EC. For the period 1974-1982 five price levels 2) were compared with the actual level:

1. The price level kept constant at the 1974 level;
2. A yearly reduction of 4%;
3. A yearly reduction of 4% with the exception of 1976 during which the 1975 level applied;
4. As 3, but the 1976 level was 1% higher than the 1975 level;
5. As 3, but the 1976 level was 2% higher than the 1975 level.

Figure 5.3 illustrates the result of this simulation.

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1) These studies are cited in Roberts, et al. (1985:119) and include an IIASA study of 1984, a study by Koester of 1977 and by Schmitz and Tangermann, both of 1979.

2) "Prices" are prices received, deflated by prices paid for inputs (Ibidem:134).

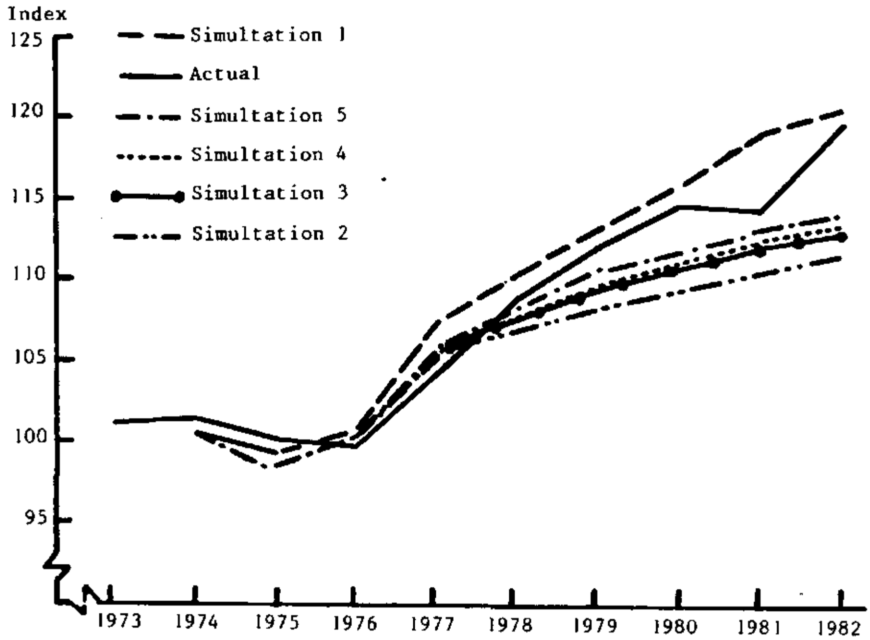

Figure 5.3 Output, actual and simulated, between 1973-1982 (under five price assumptions)
Source: Roberts et al. (1985:318)

If any conclusion can be drawn from this figure, it should be that prices do matter to the movement of total output. But two comments must be added to such a conclusion. The first is that whereas rather vigorous price reductions apply in all scenarios (except for the first), output growth is merely slowed down. E.g., in the second scenario the accumulated reduction of the real price level amounts to as much as 28%, but output still grows at a yearly rate of approximately 1%. Secondly, the BAE model contains a typical "manna-from-heaven-technology generator", in the shape of a time-index which is, positively related to input use, negatively related to the farm labour force, and not related to net investments.

Following this simulation, a projection was made for the period 1983-1996, in which a) real prices would fall by 1.5% per annum, and b) real prices would fall by 5% per annum until 1986, and by 4% per annum from 1987 onwards. Furthermore, "the annual gains in productivity that applied from 1973 to 1982 were assumed to continue" (Ibidem:319). The results of this projection are given in figure 5.4. The b-scenario was found to give a "balanced" growth of supply and demand (namely 1% a year). The authors conclude:

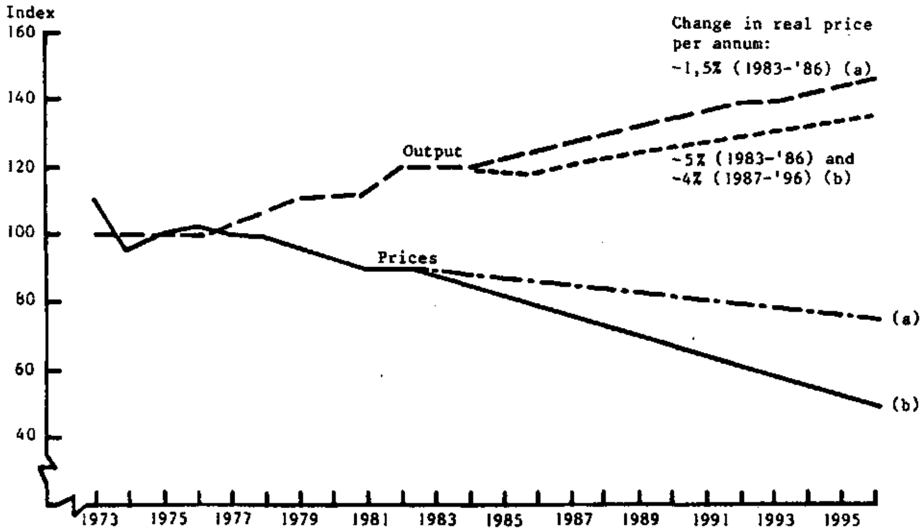

Figure 5.4 Output, actual and projected, between 1973-1996 (under two price assumptions)
Source: Roberts et al. (1985:320)

> *"One reason for such large price reductions being needed to reduce the rate of production growth by about 1 percentage point a year is the markedly reduced investment levels needed for production capacity to be consistent with lower growth. This lower investment can be induced only through reduced expectations of profitability, which require substantial real price reductions."*
> (Roberts, et al, 1985:320)

Unfortunately, the authors do not reveal the sensitivity of their computations to the elasticity chosen, although they do warn for the fact that the credibility of these projections decreases in relation to the duration of the projection period.

Comment

It is rather disappointing to discover how few analyses have been made of the price-responsiveness of supply, especially when considering the political and disciplinary value that is often attached to elasticity figures. The guesstimative character of most outcomes also illustrates the poor state supply analysis is in 1). This being said, two subsequent problems need to be solved. The first is that supply analysis should encompass (more thoroughly) all forces at work by departing from the premise that supply is the final outcome of numerous and very divergent decision-chains. The second problem concerns the central element of every-day supply analysis: elasticities. It may be true that it is not too hazardous to link supply and prices by means of such a one-dimensional figure when short term developments are analyzed. But when moving from short to long, the number of uncertain and unforeseen influences simply becomes too large to ignore. Then, elasticity figures become more and more deceiving. One of these uncertainties and unforeseen developments relates to technical change, which makes it from the economists' point of view the more interesting to relate technical with economic changes.

5.2.2.2 Prices and technical change

In spite of the rather straightforward character of the Cochrane's statement, as voiced by Tomek and Robinson, the incorporation of technical change in supply analysis complicates the matter in several ways. Halter (Heady et al, 1961:107) even believed this to be impossible:

> *".. the process of accumulation of knowledge is a unique historical process, and hence any hypothesis formulated to describe it cannot be tested. (..) Since we cannot predict by rational or scientific method the future growth of our knowledge, we cannot predict the future course of technological progress. (..) The main obstacle to making long-run predictions is the impossibility of finding a law of technological evolution."*

Nerlove and Bachman (1960) were less pessimistic, but also observed that agricultural economic theory is hardly capable of

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1) See for example the study made in charge of the European Commission (1981), in which the final outcomes of extensive calculations of the price elasticity of milk supply in the EC are ultimately represented as "expert opinions", rather than as "computed figures". The report motivates this by stating that ".. on the long run milk prices - levels as well as trends - have influence on the rate of technological and structural change (..), so that these changes cannot anymore be considered as completely exogenous factors. They will obscure the estimates of price elasticities of supply". (Ibidem:23).

explaining technical change 1), a deficiency which obviously represents a serious draw-back in the art of aggregate supply analysis.

From the literature reviewed in chapter 3 we can identify a number of features that complicate the understanding of the relationship between prices and technical change.

First of all, there is the treadmill-effect: output-increasing technologies cause a downward pressure on prices, which in its turn compels farmers to be innovators or to follow them. Consequently, the interference of technical change makes for a continuously changing relationship between supply and product prices. For example, Hill (1980:73) argued in his introductory work on agricultural economics:

> *"... it is highly doubtful whether the interests of farmers are best served by making use of the technical advance, but the spread of such advances cannot be halted. This is because the first farmers to adopt a new machine or variety of crop benefit most because they can increase their production while the price of their product is still high. Prices only start to fall when the bulk of 'middle-of-the-road' farmers take up the technical advance. The last, and most conservative, farmers (..), too, are then forced to adapt (..)".*

Secondly, we have discussed the irreversibility problem. Two dilemmas immediately come to the fore, that is, a) does fixity slow down technical change? and b) in reverse, does technical change decrease or increase fixity? At first sight, the answer to both questions will depend on the extent to which technical change involves substantial investments, for only then Johnson's divergence between acquisition costs and salvage value becomes relevant. When technical change is embodied in variable inputs, however, the fixity problem remains, be it of a different order. In many cases the quantity of inputs like fertilizers and pesticides is closely related to the specific land use, as expressed for example by the chosen grain varieties and rotation schemes. In other words, agro-biological conditions which are inherent to types of land use, may not allow for sudden changes in (variable) input combinations 2), provided, of course, that these conditions are largely insensitive to changes in the economic environment.

The analysis outlined above does not, however, take into account that technical change is a man-made affair: the various

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1) ".. relatively little analysis has been made of the rate at which (these) new techniques are adopted, and especially how this rate has been related to changes in prices" (Nerlove and Bachman, 1960:536).

2) Cf. De Wit, 1985.

kinds of decisions which lie behind the materialization of new techniques or technologies cannot be located inside agriculture, but rather in surrounding or even previously completely non-agriculture oriented institutes and private firms. According to many authors, it is nevertheless hard to conceive that product and factor prices do not exert some influence on the process of inventing and innovating. The crucial question then is: at what stage do these prices (applying to the sector in which technical change is to take place) come into the picture? Unfortunately, agricultural economics has merely touched upon this matter, without exploring it thoroughly. There are exceptions, of course. The Hayami and Ruttan approach in particular has been more or less of a milestone, but even in their work the question as to how prices influence the rate and direction of technical change is treated rather tentatively 1), especially when we focus on the production of new technologies 2). One of the best known empirical studies in this respect probably still is Griliches' inquiry into the backgrounds of the hybrid corn revolution in US agriculture. But even this study hardly goes beyond testing the sensitivity of technical change to demand conditions (see chapter 3.4.1). A more recent attempt to test the effectiveness of a price policy is undertaken by Schrader and Henrichsmeyer (1974/75). By means of a rather uncomplicated model, they computed the effects on output of several price policy alternatives for "full-time German agriculture". Production possibilities and technological progress represented one of the four (exogonous) determinants of farm output. Although they did not test the relationship between this variable and the fourth variable (terms of trade for agricul-

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1) According to Binswanger (1977:527) the question as to how economic factors contribute to the production or supply of new techniques is sufficiently dealt with by Schmookler (1966), Griliches (1957) and Ben-Zion (Binswanger and Ruttan, 1978). These studies all tested (and confirmed) the hypothesis that final demand explains "a relatively large share of the variation in the rate of technical change in the US economy" (Ben-Zion, in Binswanger and Ruttan, 1978:275). The number of studies with depth of theorization, however, remains very limited, certainly where agriculture is concerned. A very neat treatment of the relationship between agricultural prices and technical change in European history may be found in Slicher van Bath (1978), who pays much attention to the question as to why certain techniques disappear or re-appear, and to why it sometimes takes a very long time before an invention becomes an innovation.

2) Cf. Schmitt (?:16) ".. this theory of induced innovations does not make a clear distinction between application of new technologies on the one hand and investment and activities in agricultural research on the other hand".

ture), it is significant to notice that whereas the terms of trade appear to contribute substantially to the pace of output growth, they also found that the effect of price policy is quite limited:

> *"On the one hand the growth and modernisation of farms is endangered if price ratios change by more than 1,5% to 2,0% per year to the disadvantage of agriculture. On the other hand, constant or increasing real product prices would allow income growth without increases in capacity and structural change and might not give enough incentive to labour migration and structural change. Thus, agricultural price policy might envisage a decrease in the level of real agricultural product prices within a range of 0% to 2% per year to support a continuous process of structural change under present German conditions."*
> (Ibidem: 46) 1)

But like most simulation studies, these computations necessarily rest on rather stringent assumptions, for example a fixed rate of technological progress. Probably the most interesting feature of this calculation concerns the observation that structure determinants (farm size, indivisibilities, etc.) indeed can interfere with production dynamics when prices and price relations change. Thus, when technical change is fixed at a certain rate, the price-output response depends primarily on whether these structural components constitute a bottleneck. The next logical step, namely to relax the technology assumption, would consequently shed light on the degree to which technology can solve this bottleneck. But this step has not been taken by Schrader and Henrichsmeyer.

5.3 Conclusions

Clearly, the problem that has been put forward in this review, namely if and how (any change in) price policy is hampered by ongoing technical change, still is one of the least understood parts of the research agenda of agricultural economists.

If there is one conclusion to be drawn from this chapter, it must be that the relationship between prices and technical change is such a complex matter, that one-dimensional or at least simple quantitative expressions can be quite misleading when one is in-

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1) Hathaway (1969:63) thought more lightly about this issue. Judging by his argument that ".. it is probably equally true that output of modern agriculture would expand more rapidly than commercial demand even with farm prices so low as to cause great social distress among farm people".

terested in the supply response to changing economic conditions 1). In stead of serving as tools, figures such as productivity indexes, technology indexes, or supply elasticities, too often have become the end purpose of analyses.

If agricultural economics is to get a grip on the influence of prices in the process of technical change, the broad scope of the Hayami and Ruttan approach is an absolute sine qua non. This broadness, however, does not only concern the longer term to which the induced innovation theory refers. It also calls for "paradigmatical" broadness, meaning the incorporation of institutional, historical and technological features that accompany the process of technical change. Thus, when the longer term is indeed the object of analysis, one of variables that appears to be of great influence upon supply behaviour in agriculture - via its influence on structure - is the price of labour, a variable which in its turn is largely governed by general economic conditions 2). Likewise, the "technology-performance" of primary agriculture hinges strongly upon the extent and character of the integration of agriculture with surrounding firms and institutions. Thus, it can be hypothesized that the role of prices in the process of technical change, changes along with the evolution of the agribusiness complex (and subsequently the place of agriculture). For example, in the case of a highly integrated agriculture, it can be expected that technical change responds swiftly to changing (relative) prices of farm products and inputs, although this process is heavily conditioned by the economic exigencies of technology-suppliers (see also the scheme in chapter 5.2.1). In the opposite case, where primary agriculture is far less integrated, the response will at least be slower, and the conditioning by technology-suppliers less tangible 3).

As far as the shorter term, by which we mean a period of up to apporoximately two years, is concerned, the role of prices in

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1) Cf. for this matter the criticism on the alleged "price fundamentalism" put forward by De Veer (1986) and Krishna (1982). The latter argued that relative price movements "cannot by itself explain the evolution of basic scientific knowledge and the level of growth of public investment in research, extension, infrastructure, and human capital in different parts of the world" (Ibidem:237).

2) Cf. the review of De Hoogh's view, but also Johnson and Quance (1972:136) and Hayami and Ruttan. The relationship between the structure of and movements within the labour market on the one hand and the rate and type of technical change in agriculture on the other hand, nevertheless remains largely unexplored. This also applies to Marxist theory, although this approach, with its emphasis on the role of the labour reserve, seems very suited to tackle this problem (See Koning, 1986).

3) Cf. Benvenuti (1975 and 1985), and Van Dijk et al. (1986).

the process of technical change must be even more limited. For one of the crucial elements in almost all cases of decision-making that form the heart of technical change, is the formation of expectations about future developments in the fields of economy, and technology (and perhaps organization). Such conduct simply is incompatible with short-run reactions. Moreover, a short-run relationship suggests that, once economic conditions are favourable, new techniques or methods of production are almost instantly available. As we have seen in this review several times, this is too mechanic an interpretation of the induced innovation thesis.

6. General conclusion and suggestions for supplentary research

"We need a model to explain (..) how the process of technological change affects, and is affected by, the array of technical, economic, institutional, social and historical elements that make up the main fabric of rural society." (McInerney, 1984:382)

6.1 General conclusion

In due course, and all but smoothly, technical change has received a more and more prominent position on the economists' research agenda. From the classical economists to the Schumpeterians, neo-classicals and evolutionarists/institutionalists, we can now say for certain that considerable headway has been made with respect to a better understanding of what technical change is and what its origins are. As to the present state of the art we can savely say that the "black box" approach has been abandoned by and large, and that economists have not only begun to try to understand the forces behind technical change, but also - gradually - have started to incorporate "non-economic" variables in their analyses.

Nonetheless, there still is a long way to go before the alleged evasive and almost magic character of technical change is definitely dismissed. Now what are in this respect the main "lessons" to be learned from this literature survey? We will first present a few statements on the treatment of technical change from the theoretical point of view. These statements are:

1. Any economic analysis of technical change should meet a number of conditions, that is, it should
   - be able to cope with the phenomenon of continuous change;
   - reckon with the multi-faced character of technical change;
   - encompass inter-sectoral reciprocities, and
   - not hesitate to step outside the boundaries of mainstream economic theory.

2. It is crucial to acknowledge that techn(olog)ical change often serves as a general denominator for a complex string of acts and/or processes of invention, innovation and diffusion. Together they give rise to new products and methods of production. While it seems attractive or at least self-evident to subdivide them into subsequent stages, their interrelatedness would make such a procedure extremely risky. For example, it is often during the process of diffusion that additional (improvement) innovations or even inventions take

place. Thus, the concept of technical change carries with it a large number of underlying concepts of which both their complementarity and their distinctiveness should be taken into account. On this account, many attempts to measure the contribution of technical change to economic growth and productivity changes have gone wrong.

3. From the viewpoint of economics, the endogenous character of technical change is above all determined by the role it plays within overall entrepreneurial and national-economic strategies. In other words, all elements of technical change require decisions with respect to the allocation and reallocation of resources.

4. As far as technical change in agriculture is concerned, it is important to acknowledge that primary agriculture as a whole is a net-consumer of new techniques and methods of production. Predominantly institutions and firms surrounding primary agriculture generate and initiate technical change, rather than farmers themselves.

5. The relationship between prices and technical change cannot be assessed as easily as one might wish. Prices do matter, but a) within a certain range of price movements other variables determine the rate and direction of technical change, b) their influence is differentiated along the several elements of the complete process of innovation (e.g., they act upon invention in a different way than they do upon diffusion), and c) these prices in their turn undergo the influence of technical change. Furthermore, since the effects of technical change on supply are widely subscribed on the one hand, and the origins of technical change are still poorly understood on the other hand, the major tool of agricultural economists in supply analysis, the price elasticity of supply, should be handled with utmost care.

In preceding chapters, relatively much attention has been given to institutional approaches because of their propensity to take the complex character of technical change as a point of departure. However, particularly in the field of agriculture not much empirical research has yet been conducted on the basis of evolutionary premises.

6.2 Condensed outline of a supplementary research proposal

Viewed in the perspective of the results of this research report, it would be worth while to investigate the economic and institutional backgrounds of particular forms of technical change in agriculture 1). These should be techniques or methods of production which have had a marked impact upon productivity performance in agriculture. For instance, we can think of the milk tank, which - in the Netherlands - was introduced in the Sixties, after a period of extensive testing by farmers, dairy industry and engineering firms. As this form of technical change requires substantial replacement investments in primary agriculture itself, this example could well be accompanied by a study of distinct form of bio-chemical change (or several related ones), such as a specific (set of) herbicide(s) or pesticide(s).

Such case studies should cover the complete innovation process, that is, from the very first stage of production (testing, etc.) to final overall use. Emphasis should be given to a) decision criteria in all stages of the innovative process, b) the influence of changing economic conditions and c) the process of selection, i.e., why certain techniques have been developed, while others have not, etc. The main purpose of this type of research should be the reconstruction, if possible, of technological paradigms and trajectories in Dutch agriculture 2). For it is our belief that such a rather encompassing approach enables the economist to discover trends and facts of the process of technical change which are decisive to its ultimate socio-economic performance and impact.

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1) Cf. Sahal's study of the evolution in design and performance of farm tractors (1981), and Uhlin's more global (input-output) computations for dairy and cereals (Uhlin, 1985).

2) Cf. paragraph 2.4.5.

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