An Analysis of Sources of Growth in French Agriculture 1960-1984

by

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(ABSTRACT)

Agricultural production in France has increased considerably since the late fifties, turning France into a net exporter in world markets. This has generated a heated policy debate between France and the United States, centering around different views of the sources of growth in French agricultural production between 1960 and 1984. To shed some light on this debate, these sources of growth were analyzed.

A sectoral model of the French agricultural sector is developed. It is based on the assumption of profit maximization. Duality theory is used to derive short- and long-run output supply and input demand equations. All variables controlled by the decision-maker are endogenized. These include output supplies (cereals, other crop products, milk, other animal products), use of variable inputs (feeds, fertilizer-energy, hired labor), and optimal quantities of the quasi-fixed factors (family labor, capital).

The data used in estimation comes from published sources, except for series concerning French agricultural research expenditures, preferential credit rates, and agricultural labor. These were collected from unpublished sources specifically for the study.

In general, signs of estimated coefficients conform to theoretical expectations. Technological change is estimated to have played the major role in inducing production growth. Technology-led increases are attributed mostly to French research expenditures in the case of cereals, and, in the case of milk, both to French research expenditures and to transfers of technology. Credit policies have also played a role, being responsible for an estimated 8.6 and 10.4 percent of the growth in cereals and milk production.

These results have important policy implications. First, if rapid technological gains have brought France into a situation of comparative advantage, we should expect to see French policy-makers shift toward a freer market stance in trade negotiations. Second, because of massive technology transfers and shrinking export markets, the problem of protection of national research is likely to become a part of trade policy debates. Third, even if international negotiations succeeded at reducing price supports, such steps could be quickly outweighed by continual outward shifts of the supply curves if efforts to develop agricultural technology are pursued.

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Table of Contents

List of Illustrations

List of Tables

CHAPTER ONE

INTRODUCTION

I.1. Introduction

Since the late fifties, the French economy has shown a dynamism without historical precedent. The economy as a whole grew at an average annual rate of almost 5 percent from 1959 to 1984, and agricultural production increased at an annual rate of more than two and a half percent. To appreciate the relative performance of the different sectors, however, the massive and steady migration of labor from agriculture must be considered. This labor migration, combined with technical change, has contributed to an estimated average annual labor productivity increase of 7 to 8 percent a year in agriculture, compared to 5 percent in the industrial sector (Houillier). Other structural changes related to land and capital use have occurred as well, and these changes combined with agricultural policies have affected the pattern of growth of French agricultural production.

Because of the linkages among agricultural sectors of specific countries created by integrated world agricultural markets, the rate and pattern of growth of agricultural production in France has important implications on both sides of the Atlantic In recent years, the United States and the European Community (EC) have become the two main trading blocks for many agricultural commodities, whether trading with each other (e.g. coarse grains, animal feeds, beef and veal) or competing for exports in third markets (e.g. cereals, poultry, pork ,dairy products). Inside the European Community, France accounts for about 27 percent of the total agricultural production, this percentage being generally higher for the main products exported by the European Community. For example, France produces more than 37 percent of the EC's wheat.

The post-war expansion of French agricultural production has generated an on-going policy debate between France and the United States (Koester, Petit, Robinson, 1984).[1] This debate has become increasingly heated in recent years as the European Community, led by France, has become a net exporter of cereal grains. Initially, with the EC still importing grains, the effects of European agricultural policies such as the Common Agricultural Policy (CAP) price supports, were mainly to displace imported commodities. As the EC became a net exporter on world markets, the effects of these policies have become far more visible and they have led to strong reactions (Robinson, 1984).

I.2. Problem Statement

To a large extent, the policy debate between France and the United States centers around two alternative views of the fundamental sources of the observed growth in French agricultural production. Holding the view that this growth has been created by artificially high prices and that exporters can thus offer prices that do not reflect costs of production, U.S. policymakers charge the French with unfair competition in world markets. French policymakers respond that the production expansion would have occurred irrespective of price supports. They attribute growth essentially to the modernization process that has taken place: technical change, structural change (e.g., enlargment of farms) and substitution of capital for labor. Development of other sectors of the economy is also perceived to have stimulated growth in agricultural production, as a result of its influence on capital-labor substitution and labor migration out of agriculture.

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1 The debate is by no means limited to France and the EC on one hand and the U.S. on the other hand. Developing countries are also very vocal about EC trade subsidies. For a recent example, see Martin.

I.3. Justification of the study

Most recent studies of French agriculture have failed to address the above policy debate in its several dimensions. Rather, these studies have addressed primarily the effects of domestic and trade policies on specific agricultural commodities in a partial equilibrium context and assumed no technical or structural change.[2] But growth in agricultural output arises within the context of a complex set of economic forces and policy actions.

To illustrate, increased agricultural production in France may be primarily the result of basic resource utilization occurring in response to output price incentives. In this case, reduction in support prices and protectionist trade measures would be likely to reduce considerably the rate of output growth. Alternatively, increased French production may be primarily the result of technical change induced by agricultural research that also affects substitution among inputs. Lower protection may have less effect in this case.

The general economic situation is also relevant to the growth in agricultural output. If growth of the non-agricultural sector has created intersectoral wage differences resulting in labor migration out of agriculture, and substitution of capital for labor on the farm, then it may be as important as agricultural prices, input policies, or research in influencing the level of agricultural production. Returns to capital in the non-agricultural sector also affects the level of capital investment in agriculture in the long run.

Adjustment lags in the labor and capital markets also need to be taken into account because of their potential impact on output growth. To evaluate the full impact of research or price policies

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2 For example, see Albecker and Lefebvre.

on output growth, labor and capital markets must be allowed to adjust to their long-run equilibrium values.

What is needed, therefore, to address the policy debate adequately is a more comprehensive assessment of the underlying sources of growth in French agriculture. This assessment must include an evaluation of the direct impacts attributable to technical change, structural change, and agricultural and trade policies. It should include also a distinction between the short run, when some inputs have not fully adjusted, and the long run, when all inputs are in equilibrium and effects of price policies, research, and other sources of growth have been fully transmitted to the agricultural sector.

I.4. Objectives

This study has one overall objective: To assess the proportions of growth in French agricultural production between 1960 and 1984 resulting from price support policies, structural change, domestic agricultural research, international technology transfers, the influence of the other sectors of the economy through labor and capital markets, and the development of human capital embodied in the education and skills of French farmers. To help fulfill this objective, four secondary objectives are defined as follows:

1. To measure the impact of agricultural research, both domestic and transferred through internationally available technology, on the agricultural production process and output growth;

2. To identify the domestic structural and credit policies that have influenced French agriculture and to quantify their impacts on resource utilization and agricultural growth, before and after full adjustment in use of family labor and capital in agriculture;

3. To identify the interrelationships between the agricultural sector and the other sectors of the economy through labor and capital markets, and to quantify the effects of these linkages on input usage and on the rate of growth of farm output; and

4. To evaluate the impacts of the level of agricultural prices -- which are strongly influenced by the European Common Agricultural Policy (CAP) -- on agricultural growth, in light of the changes in resource utilization and output levels that have occurred for other reasons, and with and without full adjustments in the labor and capital markets.

I.5. Hypotheses

The major hypothesis tested in this study is that the increase of agricultural production in France between 1960 and 1984 resulted more from the combined effect of research, education, and other sources of structural change in agriculture, than from price and marketing policies, with their domestic and foreign trade aspects. The following corollary hypotheses to the main hypothesis are tested:

1. That the increase in agricultural production resulting from changes in technology can be attributed more to domestic research than to international technology transfers, though the latter is hypothesized to have had a significant and positive influence;

2. That French structural change and credit policies have had a direct positive impact on both the level of resource utilization in agriculture and the level of agricultural output;

3. That both labor and capital have had positive marginal products in French agriculture, so that labor migration out of agriculture has had by itself a negative impact on agricultural production

while capital intensification has had a positive impact. The net effect of this substitution of capital for labor is hypothesized to have led to an increase in agricultural production;

4. That price support policies have had a direct positive impact on both the level of resource utilization in agriculture and the level of agricultural output.

I.6. Methodology

The hypotheses of our study are addressed by employing a model of the French agricultural sector. Agricultural production is disaggregated among four major commodity groups (cereals, non-cereal crop products, milk, and non-milk animal products) by using a profit function model with separate output supply and input demand functions. Variable inputs are disaggregated into three categories (feeds, fertilizer and energy, and hired labor). Capital (building, machinery) and family labor are considered as quasi-fixed while land is viewed as fixed. The non-agricultural sectors impact the agricultural sector through the effects of industrial wage and interest rates on farm-family labor migration and capital investment.

To further describe the short-run versus long-run aspects of the model, consider a short-run supply curve that is derived from the profit function. When price increases (because of a higher price support, for example), there is movement along that supply curve and, if the supply curve is upward sloping, production increases. Adjustments in the short run occur by varying the quantity of variable inputs only. Variables relating to weather, technical change and structural policies are assumed to be exogenous since they are beyond the control of the profit-maximizing decision-maker (the farmer and, by extension, the farm sector). They are also fixed in the short run.

Over time, however, the short-term supply curve is shifted in response to several factors. First, technological innovations and structural change may increase the level of farm output for a given set of prices and fixed factors. Second, capital investment and family labor can adjust in the long run, causing further shifts in the short-run supply curve.

While technology and structural policies are treated as exogenous in our analysis, choice of the levels of utilization of the quasi-fixed factors family labor and capital is part of the long-run profit maximization optimization problem of the farmer. These choices are endogenized by deriving optimal levels of quasi-fixed factors from the estimated short-run profit function model. Thus, using the behavioral assumption of profit maximization, the model developed in this study allows us to assess the effects of price policies, technological change, and structural change on agricultural production, with and without adjustment of the quasi-fixed factors.

I.7. Overview of the dissertation

The remainder of this dissertation is organized as follows. Chapter II summarizes the French economic situation, tracing the performance of the economy since the fifties, and then concentrating on the evolution of the agricultural sector and on the agricultural policies of the period. Chapter III develops theoretical issues central to the evaluation of sources of growth in French agricultural production. Research and technical change, price stability, and transfers of labor and capital between agriculture and the rest of the economy are discussed. Adjustment lags in the labor and capital markets are also described. In chapter IV, different approaches to integrating the concerns raised in chapter III are discussed. Chapter V presents the empirical model, along with variable specifications and data sources. Chapter VI presents and discusses the results of the analysis. Chapter VII summarizes the dissertation, offers some conclusions for the policy debate that has motivated the study, and provides suggestions for further research.

CHAPTER TWO

THE FRENCH ECONOMY

II.1. Introduction

Some basic economic and demographic statistics of France are presented in table II.1. France has a population of about 54 million, compared to 56 million in the United Kingdom and 61 million in West Germany. However, because France has a far greater land mass than its main neighbors, its population density of 99 per square kilometer is far less than that of either the U.K. or West Germany, which have respectively around 234 (OECD U.K.) and 246 (OECD Germany) inhabitants per square kilometer. By comparison, the United States has a population density of 25 inhabitants per square kilometer (OECD U.S.), but an area 17 times larger than France.

Before concentrating on the French agricultural sector, an historical perspective on the performance of the French economy in the post-war era is briefly presented. The evolution of agricultural production is then considered, and the underlying factors of production are specifically examined. This section closes with a presentation of the government policies that have shaped the agricultural sector throughout the past thirty years.

Table II.1. Basic statistics of France

THE LAND		
Area (1000 sq. km)		549.0
Land in agricultural use (1000 sq. km) in 1981		317.7
THE PEOPLE		
Population in 1983 (thousands)		54,346
Inhabitants per sq. km (number)		99.0
Total labor force in 1983 (thousands)		23,306
PRODUCTION		
GDP at market prices in 1983 (billion francs)		3,957.0
GDP per head (US dollars, 1983)		9,554.0
Components of GDP at market prices in 1983 (percent):		
Agriculture		5.0
Industry		35.3
Construction		7.5
Services		52.2
		100.0
FOREIGN TRADE		
	Exports	Imports
Trade as a percentage of GDP in 1982	21.7	24.4
Main exports (imports) as a percentage of total exports (imports),1982 :		
Food, beverages and tobacco	15.9	9.7
Machinery, transport equipment	34.2	23.9
Iron, steel products	7.8	5.8
Chemical products	12.7	8.6
Textile products	3.1	---
Fuels, lubricants, etc.	---	26.8

Source : OECD economic surveys, France, July 1984.

II.2. The national context in an historical perspective

At the turn of the twentieth century, France had just begun its industrial and economic modernization, while these processes already had taken place in both Great Britain and Germany during most of the nineteenth century (Hough). This lag proved detrimental during the First World War, which found France totally unprepared for a long period of intensive warfare. The war left a deep scar, as much because of the nearly total destruction of the north-east part of the country, as because of the tragic loss of manpower. One and a half million people died in France during World War I out of a population of about 39 million.

Despite the devastation of the war, the ensuing recovery was strong and was dependent on a number of new industries (chemicals, mechanical engineering). Subsequently, the 1930's economic depression hit the country hard. It created political instability, from which the country had not recovered by the Second World War. This war found a country weakened by the previous unprecedented manslaughter and by the economic and political crisis of the previous ten years (Parodi). By 1944-1945, the French economy was more deeply affected than it was in 1914-1918. Although fewer people died, the destruction was more complete, affecting in various degrees the entire territory. By 1944, total industrial production was less than half of the level achieved in 1913 (Hough). Furthermore, communications were severed and the commercial networks both within and outside the country were lost.

Agricultural production had grown at an average of 1 percent a year between 1892 and 1915 (Carré *et al.*). After a large drop due to World War I (the level of production of 1913 was attained again only in 1930), agriculture grew at an average of 1.2 percent between the two wars. The consequences of World War II were less severe on agricultural production, and it expanded quickly afterwards: the production level of 1938 was attained again in 1949.

Overall, the reconstruction of the economy was also fast, and the ensuing economic development steady. Without taking into account the exceptionally high growth rates immediately following the war (10 percent in 1947, 13 in 1948, 7.5 in 1949), the average annual growth rate was 5 percent between 1950 and 1960 and slightly higher than 5 percent between 1961 and 1973, at which point the world energy crisis deeply affected the economy. Table II.2 places these rates in an international and historical context. Between 1961 and 1973, only Japan had a higher growth rate than France. After the general slowdown due to the 1974 oil shock, economic growth in France has averaged about the same as the other major developed countries. The forces at work in this post-war recovery are briefly examined below.

Many theses have been advanced to explain the growth of the French economy after the Second World War (Carré, Dubois et Malinvaud). The catching up of the economy with its previous growth trend was seen by some as a natural phenomena, and it is true that many believed that the rebuilding of many industries in the years following the war would ensure high growth rates. But these rates persisted through the sixties and the seventies, instead of slowing down as might have been expected (Carré *et al.*).

Another argument has been that the devastation was so great that it created a beneficial psychological shock, changed attitudes, and brought new leaders to the surface (Kindleberger). Thus, as for the other war torn nations -- West Germany, Italy, Japan -- the conditions for a rapid economic growth would have been created by the war. But, as pointed out by Carré, Dubois and Malinvaud, the rapid growth rates observed in these war torn nations were very rapid after the war because they had fallen so low. Once the reconstruction was made these nations, as a bloc, did not have higher growth rates than the other developed nations, as can be seen on table II.2.

Two other explanations for the long period of rapid economic growth in France have received more acceptance: the increase in population, and the structural reforms.

Table II.2. Average annual growth rate of G.D.P. in France and in selected other countries

Year	1870-1913	1914-1950	1951-1960	1961-1973	1974-1984
France	1.6	0.7	5.0	5.2	2.2
Great Britain	2.2	1.7	2.8	3.1	1.1
U.S.	4.3	2.9	3.2	4.2	2.6
Italy	---	---	5.5	5.2	2.0
West Germany	2.9	1.2	7.7	4.6	1.8
Japan	---	---	9.5	9.4	3.8

Sources : Parodi, for the years 1870-1960
International Monetary Fund, for the years after 1960

II.2.1. The population increase

According to Parodi, among the various forces of economic renewal and sustained growth in France, the demographic increase must be placed high, possibly even first. From 1946 to 1978, the French population increased by 13 million, which was almost as much as the total growth between 1800 and 1946. This population growth was due to migration into France (particularly from the former colonies of North Africa), but also to very high birth rates in the late forties and early fifties when they averaged 20 per thousand annually. Birth rates declined to 18 per thousand annually between 1954 and 1964, and to slightly less than 17 per thousand annually until 1974. Since 1974, there has been a substantial further drop in natality.

Despite the apparent importance of this phenomena in the process of growth, because of its demand effect, population growth may not be a key factor in the renewal of the French economy (Carré, Dubois and Malinvaud). The empirical link between population and economic growth appears to be weak, as evidenced by the following facts. The industrial power with the most rapid growth in the post-war era is Japan, which is also the country that has restricted its birth rate the most. Also, birth rates have increased almost everywhere in Western Europe since the war, but the pace of economic growth has been drastically different among its countries.

The increase in population appears to be, at best, only one of the forces behind the economic growth. It would probably not have affected the rate of growth much without the influence of other forces, the main one being the vast structural changes in the economy.

II.2.2. The structural reform

Because of the necessity of reconstructing a destroyed economy, important structural reforms were introduced in France after World War II. These reforms gave the state more pervasive control of the economy. Industries were rebuilt, as public industries (like Renault), and they often were given the status of a monopoly (e.g. airline companies, railroad company, electricity and gas companies, radio and television). The influence of the government went (and goes) beyond the industries and sectors directly under its control, due to powerful nationalized financial institutions. The state used its control to lead the reconstruction effort, compensating for the weakness of financial markets (Parodi); in 1949, 47 percent of national investment was financed by public funds. Development plans were devised, and were used to direct the reconstruction effort and to distribute financial resources, whether from U.S. aid (Marshall plan) or from domestic origin. Once reconstruction was achieved, the efficiency of the state enterprises has been debated and has become an important political issue (it was at the forefront of the national elections of 1981 and 1986). It is in this context that we can place the evolution of agricultural production in France.

II.3. The agricultural situation

During the nineteenth century, France was dominated by a rural society in which agriculture played a pre-eminent role. Even in the early 1950's, over 28 percent of the work-force was still employed in agriculture, while more than 44 percent of the total population lived outside urban areas (Tuppen). Since the 1950's, a major transformation has occurred. Agriculture currently employs less than a tenth of the active population, and 75 percent of the population lives in urban areas. Agricultural production has risen substantially, making France one of the world's major exporters of agricultural products.

II.3.1. Evolution of agricultural production

The relative importance of individual agricultural products in the total value of 1980 agricultural production is given in table II.3. One notes that three products (milk, cereal and beef) represent more than 47 percent of the total.

Between 1960 and 1980, the volume of total agricultural production in France increased by 64 percent (Bourgeois). The rates of growth (in volume produced) were consistently between 2.5 and 3 percent annually between 1950 and 1983, except for the period 1974-1977 (Bergmann 1984). Production decreased by 1.5 percent from 1974 to 1975 and by 2.6 percent the following year, before increasing by 2.1 percent between 1976 and 1977 (computed from BAC 1982). This temporary decrease in production is generally attributed to the first oil shock of 1973 and an extremely severe drought in 1976. The combination of these two events forced some enduring changes in French agriculture, causing farmers to modify their systems of production (Bourgeois).[3]

In the twenty-five years 1950-1975, the pattern of French agricultural production also changed more than it did during the seventy years prior to World War II (Gervais, Jollivet and Tavernier). Cereal production went from 14 million tons in 1938 to 35 million in 1977; corn, a new crop in France, increased in production from 0.5 million tons to 8 million tons; red meat (beef and pork) production doubled from 1.6 million to 3.2 million tons, while poultry production increased by a factor of four and milk production by a factor of two (Rivière). These examples illustrate that the production increase in French agriculture since World War II has not been uniform across commodities. In general, the increase has been more even for animal than for plant products (Bourgeois). The diversity in growth rates is shown in table II.4, in which the evolution of the quantities of eleven agricultural products delivered to the market between 1960 and 1984 are

[3] Also, the general economy was much more depressed after the first oil shock, which altered the context in which the agricultural sector was operating.

Table II.3. French agricultural production in 1980

Product	% of total value
Cereals	17.4
Fruits and Vegetables	10.6
Wines	10.1
Other Crop Products	5.0
Sugar Beet	3.1
Total Crop Production	46.2
Milk	18.0
Beef	12.3
Pork	7.0
Veal	4.8
Poultry	4.9
Other Livestock Products	4.1
Eggs	2.7
Total Livestock Production	53.8

Source : INSEE, 1984.

reported. Production of cereals increased over 200 percent while production of fruits and vegetables increased less than 5 percent.

II.3.2. Evolution of agricultural prices

The large increase in production discussed above occurred in a context of declining real output prices. Figure II.1 presents the evolution of the prices of cereals (P_C), other crop products (P_V), milk (P_M), and other animal products (P_N) between 1959 and 1984. Prices are given as indexes, with value 1 in 1970. The downward trend appears the strongest in the case of cereals. If we average the first three years and the last three years to reduce yearly fluctuations, cereal prices have declined by 31.85 percent over the twenty-five year period. Similar computations show that prices of non-cereal crop products, milk, and other animal products have decreased respectively by 5.39, 18.14, and 23.77 percent over the same period. This is due to the high inflation prevalent in France during the time, and also to increases in productivity which reduced costs, increased profits, and consequently increased production and reduced prices.[4]

On the input side, real prices have followed a different pattern. Figure II.2 presents the evolution of the aggregate prices of fertilizers and energy (r_F), feeds (r_D), and hired labor (r_H) over the period 1959-1984. The cost of labor is seen to have increased dramatically, by almost 300 percent, while the prices of feeds and fertilizer-energy have declined by 20.55 and 4.33 percent, respectively.

A comparison of figure II.1 and II.2 shows real output prices declining over time with respect to real input prices. Until 1973, prices of industrial inputs were decreasing in real terms.[5] In 1974, they sharply rose but only to the level they had reached in 1962. On the other hand, output prices

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4 As is explained later, output prices are largely determined by support prices set at the European Community level. It is unlikely that price determination would be done without any consideration of the evolution of farm profits.

5 Industrial inputs are the largest input category, in value.

Table II.4. Evolution of quantities delivered to the market

	(Percentage increase)			
	1960-1970	1970-1980	1980-1984	1960-1984
Cereals	+ 100.6	+ 52.1	+ 21.2	+ 269.9
Fruits and Vegetables	+ 12.3	-7.9	+ 0.5	+ 4.8
Wines	+ 18.4	+ 14.8	-9.8	+ 22.6
Sugar Beet	+ 35.6	+ 54.0	+ 5.5	+ 111.8
Total Plant Products	+ 39.3	+ 24.2	+ 7.3	+ 85.6
Milk	+ 35.1	+ 26.1	+ 0.1	+ 70.5
Beef and Veal	+ 24.2	+ 21.9	+ 8.8	+ 65.3
Pork	+ 7.9	+ 37.3	-2.8	+ 43.8
Poultry	+ 47.1	+ 80.9	+ 11.1	+ 195.8
Eggs	+ 23.5	+ 28.8	+ 5.5	+ 67.8
Total Animal Products	+ 22.3	+ 28.8	+ 4.6	+ 64.8
Total Agricultural Products	+ 29.4	+ 26.7	+ 3.5	+ 69.7

Sources : Bourgeois, for 1960-1980.
FAO Production Yearbooks, for 1980-1984.

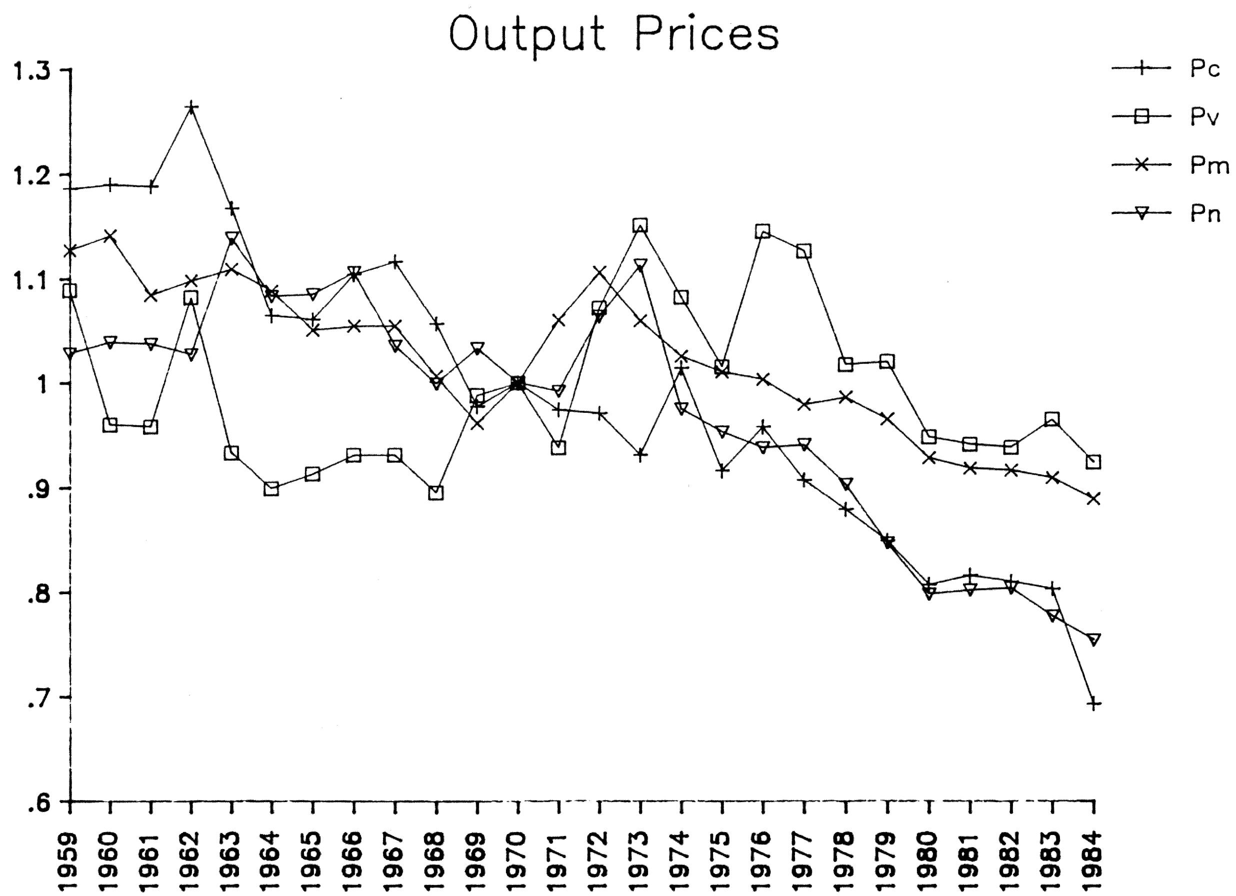

Figure II.1. Real output prices

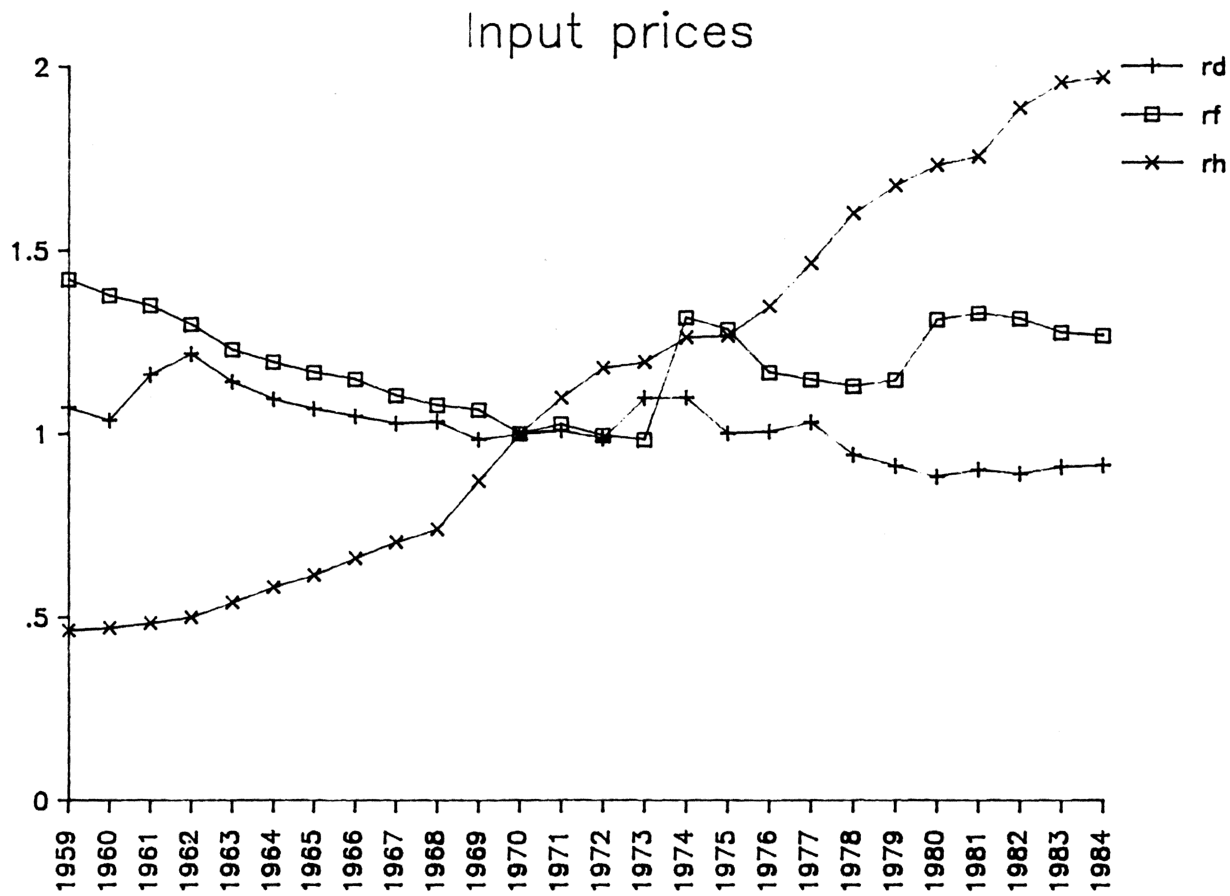

Figure II.2. Real input prices

have fallen. Bourgeois computes that output prices were slightly decreasing in real terms (−0.65 percent per year) until 1973. From 1973 on, the drop was 3.2 percent per year. However, these numbers may not accurately represent the evolution of farmers' profits. In fact, this worsening of terms of trade for the agricultural sector may not put them into that much worse a situation if technological change occurs. Their situation depends on the relative magnitude of the rate of technical change and on the rate of deterioration of terms of trade, and on the resulting impact on farmers' profits. More evidence, therefore, is needed to establish the causal relationship between changes in terms of trade and farmers' income.

II.3.3. Changes in input usage

II.3.3.1. Land

The total area of France is almost 55 million hectares (table II.1), 58 percent of which are in agricultural use. If woods, forests, and other pastured land are included, agricultural land covers almost 90 percent of the total land base. Between 1950 and 1980, however, a little more than one million hectares were converted to non-agricultural, forestry, or pasture use, as industrial growth occurred. Only one half of this came from agricultural land in use (Graph Agri), so that agricultural land in use has only been reduced about one hectare per thousand during the past 30 years.

II.3.3.2. Labor

The number of people working in agriculture has steadily declined since the fifties. Between 1950 and 1975, it went from more than five million people to barely more than two million. This 60 percent reduction is the same as the decrease observed during the previous 100 years, 1850-1959 (APCA 1978). The agricultural working population fell from 20 percent of the work force in 1962 to 9.5 percent in 1975, and to 7.7 percent in 1981 (INSEE 1981). More generally, employment has shifted from the primary sector of activity (agriculture, fishing, and extractive industries) to the tertiary sector (services), as evidenced by table II.5.

In 1982, of the 1.8 million agricultural workers, 56 percent were "chefs d'exploitations", i.e. self-employed farm owners or managers, 27 percent were "aides familiaux", i.e. members of the family other than the "chef d'exploitation", and 17 percent were "salariés", i.e. wage-earning farm employees. These three categories have seen their relative importance change, as can be seen in table II.6.

The family labor and the wage employees have declined more than the owner-managers. As far as the family labor is concerned, the reduction is mostly due to young people leaving agriculture for other careers (Parodi). A farm disappears when the farmer retires, and nobody is there to succeed him. This lack of succession is caused by decisions made 15 or 30 years earlier by his children, confronted with the question of whether the farm will allow them to reach the standard of living they desire. Farms judged too small thus tend to be sold and combined with other farms. Thus, the migration of young people out of agriculture contributes to a diminution of the number of small farms.

Comparing the labor migration out of agriculture with the growth of the agricultural sector leads to the question of whether this growth is a cause or a consequence of the labor out-migration. According to one hypothesis, technical change in agriculture has freed a substantial proportion of the agricultural labor force for non-agricultural work, thus fueling the overall economic growth of the economy. According to a second hypothesis, the rapid increase in production in the rest of the economy has offered opportunities for work, allowing agriculture to shed a disguised unemployed work force and offering better-paid jobs to young farmers. The implication is that this would have occurred irrespective of technical change in agriculture and that the labor transformations in the agricultural sector are therefore simply a result of the overall French economic growth. Carré,

Table II.5. Employment distribution in France, 1946-82

	1946	1962	1982
	--------percent--------		
Primary (agriculture, fishing, extractive industries)	34	22	10
Secondary (transformation industries, including building and public works)	31	37	32
Tertiary (services, transport, including water, gas and electricity services)	35	41	58
	100	100	100

Source: Dyer, and INSEE, Annuaire Statistique de la France, 1984.

Table II.6. Evolution of the agricultural labor force, 1954-1982

	1954	1962	1968	1975	1982
	million people				
Owner-Managers	1.9	1.7	1.4	1.1	1.0
Family Members	2.1	1.4	1.1	0.5	0.5
Wage earners	1.1	0.8	0.6	0.4	0.3
Total	5.1	3.9	3.1	2.0	1.8

	1954	1962	1968	1975	1982
	percent				
Owner-Managers	37.3	43.4	46.3	56.6	55.8
Family Members	41.2	35.3	34.9	24.9	27.2
Wage Earners	21.5	21.3	18.8	18.5	17.0
Total	100.0	100.0	100.0	100.0	100.0

Sources : Klatzmann, J. L'Agriculture Française, Ed. du Seuil, 1978, and INSEE, 1984.

Dubois and Malinvaud cite evidence supporting the second hypothesis. But these authors also point out that the industrial growth does not fully explain the transformation of the agricultural sector.

While the agricultural population has decreased, part-time farming has become more common (APCA 1978). In 1955, almost 80 percent of the owner-managers worked full time in agriculture, but this percentage dropped to 61 in 1979. For family members, the full-time proportion is even lower, 41 percent for men and barely 9 percent for women. Despite this, however, the number of small farms has declined as noted above.

With a declining labor force and an increasing production, measures of labor productivity have increased. Vial estimates that the production increase per worker has averaged some 8 percent per year between 1955 and 1980. Houillier compares this rate, that he estimates at 7 percent for the period 1962-1975, to the 5 percent that characterized the industrial sector for the same period.

The following sections will investigate the factors that have made possible the increase in labor productivity in French agriculture. These factors are increased investment in machinery, buildings and equipment, increased use of purchased inputs (fertilizers, energy products, animal feeds), the enlargement of farms, and technological change.

II.3.3.3. Capital

The rapid increase in production that has occurred despite labor out-migration has been possible in part because of an increase in capital investment far exceeding that seen in the past. On a per-farm basis, investment in machinery and equipment increased 2.7 times between 1960 and 1980 (Bourgeois). During the same period, the real value of machinery per farm almost quadrupled and the real value of equipment more than tripled. Investments have been split approximatively two-thirds and one-third respectively for machinery and building equipment (APCA 1978). The most notable fact is that there are now more than 1.5 million tractors, compared to fewer than 30,000 before the war (Bergmann 1982). Tractors have almost totally replaced draft animals, which used to consume the production of at least three million hectares, approximately one-tenth of the agricultural land (Dumont).

Compared to the rest of the economy, capital investment in agriculture was quite impressive (table II.7). Nevertheless, the volume of investment per worker has been reduced since 1974. This is generally attributed to the financial difficulties encountered by the farmers (Bourgeois), when the dramatic rise in energy prices had drastic consequences on farm income. Until 1973, changes in agricultural prices and prices of industrial inputs used in agriculture followed a similar pattern. In 1974, with the oil crisis, prices of agricultural inputs increased at a faster rate than those of agricultural products, a trend that has continued since that time (see section II.3.2). Bourgeois argues that, when placed in a tighter financial position, producers reduced their investments, and that many of them went more deeply into debt. However, as discussed above, the increasing wedge between input prices and agricultural product prices does not necessarily lead to deteriorating farmers' income.

II.3.3.4. Variable inputs

The use of intermediate products purchased from other sectors increased by an average of more than 6 percent per year from 1950 to 1980 (Carré, Dubois and Malinvaud). The increase was especially rapid in the early years, averaging 7.2 percent a year from 1960 to 1973 and a more modest 3.5 percent from 1973 to 1980 (Bergmann 1984).

Intermediate products mostly consist of fertilizers, pesticides, and animal feeds. The increase in cereal production in France went hand in hand with the five-fold increase in fertilizer use, which occurred between 1950 and 1973. This increase in fertilizer use has slowed since 1973, presumably

Table II.7. Evolution of capital per worker

	(% per year)	
	1963-1973	1973-1978
Agriculture	8.6	6.9
Manufactories	4.9	5.8
Industry as a Whole	3.9	4.5

Source : Dubois, P., INSEE.

in response to price changes mentioned above. The consumption of animal feeds has followed a similar pattern. The almost 11 million metric tons of feed consumed in 1973 was almost ten times greater than the feed consumption in 1954 (Gervais, Jollivet et Tavernier). This, of course, contributed to the growth observed in beef, pork and, especially, poultry production.

The value of intermediate inputs as a proportion of the value of final production has been increasing since the 1950's. It went from 19.6 percent in 1954 to 25.2 percent in 1966 and 40.7 percent in 1975 (APCA 1978). It reached 44 percent in 1977 (Houillier), and was almost 50 percent in 1980 (Bergmann 1982). If we add to that the value of capital investments made by farmers, which increased from 10 percent of the value of final production in 1960 to 15 percent in 1977 (APCA 1978), we find that the total value of capital inputs increased from about 40 percent of the value of final production in 1960 to almost 70 percent in 1977. This demonstrates the increasing capitalization of French agriculture.

II.3.4. Structural changes

As in many other European countries, modernization of French agriculture has been affected by the pattern of land distribution. As table II.8 reveals, France in the 1950's was characterized by a large number of agricultural holdings, many of which were very small. Furthermore, many farms were subdivided into numerous non-contiguous parcels. It has been estimated that, in 1955, up to 18 million hectares of farmland were divided parcels that could have been consolidated (Tuppen). In certain areas, Chombart de Lauwe reported that it was fairly common (in 1976) to see 20 hectare farms split in as many as 50 small fields, many of them apart from each other. This situation was the consequence of many factors, mostly the legacy of medieval open field agricultural systems and the result of complicated inheritance laws. These conditions made impractical (and uneconomical) the introduction of mechanization. This led the government to pass legislation accelerating consolidation and also favorizing an increase in average farm size.

Table II.8. Distribution of agricultural holdings by size

Size in hectares	Number of farms (thousands) 1955	1970	1981	Percent of total 1955	1970	1981
< 5.0	807	493	327	35	31	27
5-9.9	482	251	151	21	16	13
10-19.9	540	355	228	23	22	19
20-34.9	298	263	225	13	16	19
35-49.9	83	107	114	4	7	9
50-99.9	76	93	117	3	6	10
> 99.9	21	27	35	1	2	3
TOTAL	2,307	1,589	1,197	100	100	100

Source : Ministère de l'Agriculture, Recensement Général de l'Agriculture 1979-1980, 1981, and INSEE, 1984.

Table II.8 shows that the number of farms declined to around 1.2 million by the early 1980's. Whereas in 1955 about 56 percent of all farms were less than 10 hectares and only 8 percent were above 35 hectares, these proportions changed to 40 and 22 percent respectively by 1981. The number of farms between 20 and 35 hectares remained fairly constant. Thus, the overall change is accounted for essentially by a spectacular decline in holdings below 20 hectares and a marked rise in those above 35 hectares.

Houillier estimates there has been an increase in the average size of farms from 15 to 25 hectares in the past 25 years. He attributes this to a rapid decrease in the number of small farms, a fairly stable number of holdings between 20 and 50 hectares (with a tendency of enlargment within that range), and an increase in the number of farms above 50 hectares. The growing significance of larger production units is indicated by the fact that approximatively 42 percent of all agricultural land is concentrated in farms exceeding 50 hectares, which also account for more that a third of the total value of output (Chombart de Lauwe). Sixty percent of gross agricultural receipts are concentrated in 200,000 farms (Bergmann 1984).

A potential problem inherent in the statistics presented above is that, for statistical purposes, a farm is considered any production unit with at least one hectare (2.47 acres) of agricultural land, or one milking cow, or one tenth of an hectare of quality vineyard (Bergmann 1982). A perhaps more realistic definition has been proposed by Bergmann (1984). He suggests that a farm be considered those holdings employing at least one "work-unit", i.e. the equivalent of one full-time worker. Under Bergmann's definition, there were only 1.1 million farms in 1970, and 0.8 million in 1984. According to Bergmann, the number of such holdings decreased faster than the number of small units under the official definition, with a drop of 3.1 percent a year during 1970-1975 and 2.1 percent per year during 1975-1979.[6]

[6] Appropriate statistics were not kept prior to 1970.

Related to the issue of number of farms is the phenomena of part-time farming. It was mentioned above that almost 40 percent of French farmers (owner-managers) are involved in another activity. This percentage was obtained using the usual definition of a farm (more than one hectare, etc.). Undoubtedly, the proportion of part-time farmers whose holdings are very small is high. Also, part-time farming is a solution to maintaining a rural population in the poorest areas (APCA 1978) whose contribution to total production remains marginal.

II.3.5. Technological change

Technical change is an important factor explaining the increase in agricultural production in France. This section is divided in two parts. The first describes the pace of technological change in French agriculture over the past twenty-five years. The second concentrates on the causal mechanisms of technological change, particularly on the effects of research, extension, and education.

II.3.5.1. The pace of technological change

The rapid capitalization of French agriculture has been made possible by a myriad of technological improvements. Parodi has observed that most of the productivity increases have occurred since 1950. Much of the labor productivity increase can be attributed to large-scale and widespread advances in mechanization (Chombart de Lauwe). Initial progress along these lines was slow, despite the priority given to mechanization by the first national plan. Draft animals still provided the major source of energy in the early 1950's (Gervais, Jollivet et Tavernier). Progress became rapid, evidenced by the increase in the number of tractors mentioned earlier and presented in more detail in table II.9. This replacement of animal by mechanical traction -- facilitated by the development of France's agricultural machinery industry -- had a complementary effect on the adoption of other technologies, allowing for example a better use of fertilizers, of pesticides, of new varieties, etc..

This trend also has been accompanied by a significant biological revolution (Tuppen). Yields of major cereals have increased substantially through the introduction of improved hybrid varieties, in conjunction with larger quantities of chemical products. This is evidenced by the rise in application of fertilizers reported in table II.10 and the increase in yields of some cereals shown in table II.11.

In the same way, animal production has been made more efficient through increased specialization of breeds, together with improvements of buildings and facilities (Le Roy). Production methods have been more standardized and the quality of output has increased. This has been made possible in part by a development of animal feed systems adapted to higher performing breeds, which has resulted in growing soybean imports from the United States.

II.3.5.2. The supply of technological change

It is clear from the increased importance of mechanical and chemical methods used by French farmers that much of the technological change adopted in agriculture has had its origins outside of the sector. Agriculture has benefited from progress made in various industries. Research at the agricultural research institutes has developed and adapted innovations to the needs of farmers. Also playing an important role have been the extension and education services which have popularized the new techniques and helped farmers to adapt them and to become more economically efficient.

Agricultural research is almost totally monopolised by "l'Institut National de la Recherche Agronomique" (INRA). This institute was created in 1946 by integrating various agronomic laboratories. Its activities now encompass all the areas of agricultural research, from production

Table II.9. Number of tractors in operation

	Total Tractors
1955	337,000
1963	950,000
1970	1,200,000
1975	1,346,000
1980	1,485,000

Source : Tuppen.

Table II.10. Consumption of fertilizers

Agricultural Year	Total Consumption (thousand tons)
1954/5	1,470
1959/60	2,064
1964/5	3,088
1969/70	4,220
1974/5	4,679
1981/82	5,570

Source : INSEE, Annuaire Statistique de la France (various volumes).

Table II.11. Increase in yield of selected cereals

	Yield (tons/hectare)		
	1950	1970	1981
Wheat	1.8	3.4	4.8
Barley	1.6	2.7	4.2
Corn	1.2	5.1	5.6

Source : Tuppen.

techniques to agricultural economics. Table II.12 summarizes the evolution of the INRA. In 1976, its budget represented 12 percent of the total scientific research in France (Chombart de Lauwe). The increase of public research expenditures has been tremendous. In nominal terms, INRA's budget went from 10 to 790 million francs between 1956 and 1979. In real terms, the data collected for this study shows an increase of more than 600 percent in 25 years (see table VI.4).

Two other public research institutes deserve mention. They are small, one being specialized in agricultural machinery (31 researchers in 1976), the other being concerned with water resources and forests (around 100 researchers). Finally, private research is also of some importance, with "technical institutes" specializing in varietal development or machinery, and financed by the corresponding industries. These institutes sometimes cooperate with the INRA, but data on their budgets are very hard to obtain.

Salesmen and cooperatives have played -- and are still playing -- an important role in the diffusion of new techniques. Thus, the use of tractors and other mechanical equipment, fertilizers and insecticides, veterinary products, and animal feeds has been stimulated by the firms producing these products, literally selling them door-to-door.

The provision of public extension in France is the object of many criticisms (Chombart de Lauwe), mainly because of its lack of organization. There is a national association for agricultural development, ANDA, but it controls only part of the actual effort of dissemination of new technologies. For example, in 1975, the amount spent by ANDA on extension work was 275 million francs, while the financing of all extension efforts was estimated by Chombart de Lauwe at 817 million francs. Extension work among the various organizations (including INRA) lacks coordination, making it very difficult to evaluate the extension efforts.

Education plays an important role in helping farmers to adapt to a world of new and constantly changing technologies. But, in 1975, 95.6 percent of French farmers had not received any formal

Table II.12. Evolution of INRA

	1956...	1973	1974	1975	1976	1977	1978	1979
Number of workers	1500...	6068	6198	6327	6505	6776	6920	7096
Number of researchers	339...	983	993	993	1058	1106	1139	1171
Budget (million francs)	10...	325	362	434	515	619	700	790

Source : Chombart de Lauwe, and APCA 1980.

agricultural education, only 2 percent had a technical degree -- the equivalent of 1 to 2 years of college in the U.S. -- and only 0.4 percent were college graduates (Chombart de Lauwe). This data again includes those farmers whose holdings are very small, and for whom agriculture is only a small part of their income. Nevertheless, these numbers are very small.

Beginning with a series of laws in 1960-1962, agricultural education has been given an institutional structure. Besides agricultural colleges, whose enrollment has been increasing, a continuous education program has been established. It plays an important role, because access to many sources of credit is conditional on participation in these continuous education programs. In 1978, 31,894 farmers participated in these programs compared to 6874 in 1970 (APCA 1980). These programs are increasingly popular, and may be more efficient in providing farmers the training they need than most agricultural colleges, which may be too theoretical in their approach to problems.

II.4. Agricultural policies

The importance attached to the modernization and expansion of French agricultural production has been emphasized throughout the post-war period, but active policies to aid agriculture go back to the 1930's (Hough). Nevertheless, the most significant policy changes began in the late 1950's and early 1960's. As discussed below, major protective measures have been developed at the European level. Prior to those measures, most French policies were designed primarily to facilitate structural change. These policies are presented first, followed by a discussion of European Common Agricultural Policy.

II.4.1. French policy measures, 1948-1968

For ease of exposition, French agricultural policy can be disaggregated into its three main components: price, structural and credit policy. These policies, of course, frequently interact and complement each other.

II.4.1.1. Price policy

Price support policies began to appear in the early 1950's as agricultural production started to increase significantly, lowering prices for beef, veal and pork (Parodi). After a few limited local interventions, some broader institutions were created to intervene in agricultural markets. Interventions were limited to one product, or a group of products. The objectives of this system were two-fold: to help producers through floor prices, and to help consumers through use of ceiling prices. This system was in effect until the Common Agricultural Policy (CAP) of the European Community began in 1962.

An important "orientation law" -- similar to a U.S. farm bill -- was passed in 1960. It created FORMA (Fonds d'Orientation et de Régularisation des Marchés Agricoles), whose role also has been to intervene in agricultural markets, but it is not limited to a particular category of products. The coordination of the various intervention institutions has been difficult (Chombart de Lauwe). FORMA now dominates, having become the channel for EC funds for market intervention in France.

There is no doubt that these institutions caused agricultural prices to drop less than they would have in a free market, and also reduced price fluctuations (Parodi). These institutes thus have improved the average income of farmers, but there is a question of who has benefited. Brown, quoted by Parodi, believes that those who have succeeded in influencing the public authority have benefited most. These have been essentially grain producers, who for the most part operate large farms. Price policies, instead of helping the poorest, may instead have helped them to disappear by reducing their competitiveness.

II.4.1.2. Structural policy

Consolidation of farms has been (and still is) a slow and difficult process. This is due to its high financial costs (redesigning roads, for example), and to the reluctance of many farmers to exchange parcels, whether because they overestimate their land quality or because they are sentimentaly attached to their land. In 1976, about 10 million hectares had been consolidated, but it was estimated that an additional 18 million were still in need of consolidation (Chombart de Lauwe). By the end of 1983, about two million more hectares had been consolidated.

Despite its price support aspects, the 1960 law was primarily designed to influence the structure of French agriculture. The official objective of the law was to work toward parity between agriculture and the other sectors of the economy. The small size and fragmentation aspect of most farms was seen to be the major hurdle to overcome (Tuppen). Since 1960, however, market forces have acted as a natural stimulus to a decline in the number of holdings and to a general enlargment of remaining farms. These trends have been encouraged by increased mechanization and associated economies of scale. The law of 1960 (and another in 1962) was aimed at facilitating these changes. Two other mechanisms have been significant as well.

First, a series of "Sociétés d'Aménagement Foncier et d'Établissement Rural" (SAFER) was established. The SAFERs are regional bodies empowered to buy up land as it comes on the market, subsequently redistributing it to enable the enlargment of farms. A SAFER may pre-empt other potential purchasers, although they affected only 16 percent of all agricultural land sales between 1962 and 1975. They may construct and offer for sale the equivalent of new holdings.

Sales are often made to young farmers, because of the pressure of farm unions, but also to qualified older farmers. The action of the SAFERs has been somewhat limited by a shortage of funds (Chombart de Lauwe). By 1978, SAFERs had enabled some 106,000 farms to be enlarged and had bought and sold some 15 million acres. This was around one-tenth of the land that had come to the market (Hough). By 1978, they were involved annually in 26 percent of land sales.

Second, elderly farmers have been encouraged to accept early retirement and to pass on their farm (sometimes through the SAFERs) to younger farmers. A special fund was established, the "Fonds d'Action Sociale Pour l'Amélioration des Structures Agricoles", FASASA, to finance the payment of early or supplementary pensions for farmers 65 and older -- the "Indemnité Viagère de Départ", IVD. Between 1963 and 1970, farmers benefiting from IVD left 5.1 million hectares out of a total of 9.7 million hectares made available by retiring farmers (CNSEA). Thus, in these seven years, 16 percent of the agricultural area has been affected by IVD. The land thus freed has been used mostly for enlarging other farms (56 percent), or made available to new farmers (38 percent). However, Chombart de Lauwe points out that 60 percent of the enlargments and 85 percent of the new farms have been made by children or family members of the retiring farmer. Those changes would have occurred anyway, and the IVD only accelerated them. If those operations are excluded, the area affected is only 1.7 million hectares (instead of 5.1).

In addition to the preceeding policies, French law has encouraged collaboration between farmers through the creation of "Groupement Agricole d'Exploitation en Commun", GAEC, a system established by government legislation by which farmers work their holdings jointly and can, in principle, realize certain economies of scale. These have not been very successful, however, perhaps because of the unwillingness of farmers to share their decision-making power (Chombart de Lauwe). Furthermore, 84 percent of the GAECs are familial, i.e. formed by father and son(s) or between brothers, probably because it facilitates succession, but this does little to improve farm structures.

II.4.1.3. Credit policy

Credit policy is administred by a large financial institution, known as the "Crédit Agricole". It consists of 3000 "caisses locales" (comparable to local banks), grouped into regional structures, the latter being dependent on a national decision center, the CNCA. The "Crédit Agricole" is thus both the credit institution used by farmers and the financial instrument of agricultural policy (OECD, 1970). It is basically a monopolist if one considers that it provides around 70 percent of all farm loans compared to 14 percent for all other banks. The remaining 16 percent consists of short-term loans against purchases or of loans from individuals -- usually family members (Chombart de Lauwe). Table II.13 shows the repartition of loans made by the "Crédit Agricole" according to their use. The equipment loans, perhaps the most useful for the modernization of agriculture, represent only some 40 percent of the total. Land loans account for a large percentage, and demonstrate the desire of farmers to buy land. They are also a consequence of the structural policy discussed earlier, because most of the SAFER's sales involve a loan by the "Crédit Agricole". Many of these loans are granted at below market rates. Preferential rates apply to various policy instruments (the creation of a GAEC, for example, gives access to preferential rates on equipment loans by the "Crédit Agricole"). These preferential loans are estimated to represent between 60 and 70 percent of the total of the loans administered by the "Crédit Agricole". It is important to recognize that the gap between the preferential rate and the market rate was between 4.5 and 11 percent in the seventies, which explains their popularity with farmers. Most short-term loans made by farmers do not qualify for preferential rates, and are therefore made at prevailing market rates.

II.4.2. The Common Agricultural Policy

The CAP represents a vast topic, addressed by an enormous literature, and the discussion here

Table II.13. Loans provided by the Credit Agricole

	(percent)		
	1970	1976	1977
Equipment Loans	40.8	40.7	37.5
Land Loans	24.6	22.1	21.9
Habitation Loans	18.1	15.2	13.8
Disaster Loans	3.7	5.7	14.0
Short-term Loans	12.8	16.3	12.8
	-----	-----	-----
	100.0	100.0	100.0
Total Value (Million Francs)	33,585	75,471	84,359

Source : CNCA, l'agriculture Française et son financement, 1978.

will therefore be selective.[7] Recall that the European Community was established in 1957 by the treaty of Rome. At that time, only broad objectives were agreed upon, and it was not until 1962 that the CAP was established. The CAP was based on three principles:

(i) the principle of unity of the market, which has been implanted through the gradual harmonization of farm prices in member states;

(ii) the principle of Community preference, implemented by a system of variable levies; and

(iii) the principle of financial solidarity, which was reflected in the setting up of the European Agricultural Guidance and Guarantee Fund (known usually by its French acronym FEOGA).

In this section, how these principles have been applied in the market and price policy of the CAP will be examined. Then, a few facts about the budget of the Community and how it affects France will be presented.

II.4.2.1. The market and price policy

Agricultural markets throughout the Community are artificially manipulated to ensure high prices and "guarantee adequate incomes for producers", one of the publicized objectives of the CAP. This result is achieved partly through a system of official purchases of surplus products within the Community, at predetermined support prices, and partly through the imposition of taxes on imports from outside the Community. These two key elements are now presented in more detail.

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[7] An excellent reference for additional information is the book by Harris *et al.*, which is abundantly used in the presentation herein.

II.4.2.1.1. The price support system

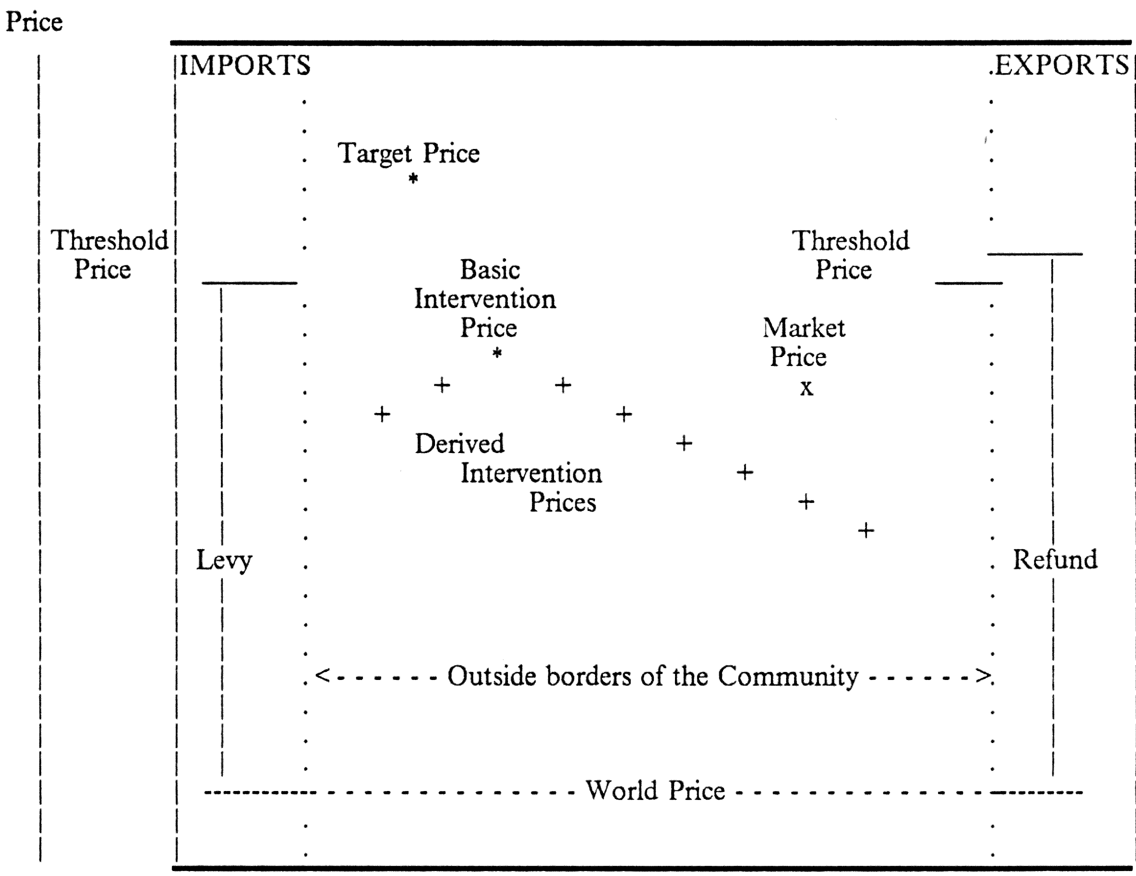
Almost every product is affected by this system, that applies to almost 90 percent of the value of agricultural production (Chombart de Lauwe). The system is very complex, since each product (or market) is affected by a specific set of legislation. Nevertheless, the operations are similar for all the major products, so that one example will be enough to illustrate how the system works in most cases.

The price system for cereals is presented in figure II.3. The price is formed freely, on the market, but can vary only within a range. Three prices are used in the system:

1. Target prices. These represent the return per unit desired for producers, i.e. the levels which domestic market prices should attain. However, target prices as such do not have any market significance because they do not trigger policy actions. Their significance lies in the fact that they are the reference point from which the other institutional support prices are derived;

2. Threshold prices. These represent minimum entry prices for imports from third countries, and apply at Community frontiers with the rest of the world. They are set at such a level that target prices cannot be undercut by third country exports, being calculated from target prices and taking into account internal distribution costs. Under usual conditions, threshold prices are the ceiling for EC internal market prices because, should EC domestic prices rise above it, then world supplies would be drawn in;

3. Intervention prices. They represent minimum market prices. National intervention agencies have an obligation to buy, at that price, Community produce offered to them -- this being an open ended commitment for cereals and, until recently, for milk. The basic intervention price is fixed in the area with the least adequate supplies. Intervention prices in other areas (derived



Source: Chombart de Lauwe

Figure II.3. Price mechanisms for wheat

intervention prices) are computed by making allowance for transportation costs, and will always be lower than the basic intervention price (see figure II.3).

Thus, there is a price band that defines the range within which domestic market prices are free to fluctuate, while being maintained above world market prices. The bounds of the price band are set by the Community's institutional support prices. The ceiling on domestic market prices is set by the institutionally determined minimum import prices at which third countries supplies are allowed to enter the EC threshold prices. Conversely, the floor is set by the institutionally determined minimum market prices at which governments have a commitment to intervene (intervention prices). For most commodities, the minimum import price is some 20 to 30 percent above the minimum domestic market price (Harris *et al.*).

II.4.2.1.2. The trade mechanisms

The EEC system of price supports can function only with protection from the outside, which is therefore built into the system. As figure II.3 shows, the threshold price is the price at which imports can enter the market. As already mentioned, the threshold price is fixed so as to represent the target price minus all the costs (unboarding, distribution costs, taxes, etc.). The difference between the threshold price and the world price constitute the levy, which is variable since world prices are variable. The levy is directly perceived by the Community.

It is important to notice that, since the market price is below the target price as long as there are no domestic surpluses, the system guarantees the principle of Community preference: imports from third countries will reach the domestic market at prices superior to the market prices, thus effectively protecting domestic producers.

The other consequence of the system is that farmers produce without considering the market, since the Community guarantees the purchase of their products if prices fall to the intervention price. When supply exceeds demand, the Community is thus bound to buy increasing quantities from the market, quantities that need to be stored or exported. It is obvious that the Community will not be competitive as a seller on world markets, until the gap between its internal prices and world levels can be bridged. This difference is paid as a subsidy to traders when they export the product from the Community. These subsidies -- known as export refunds -- are not viewed as subsidies by the Community, but only as a means to enable Community exporters, buying domestic production at high internal prices, to compete on world markets (Harris *et al.*). Needless to say, the Community's competitors on world markets have quite a different view of the export refunds.[8]

It is easy to see why the EC system, designed when Europe was a net importer of most agricultural products, has become difficult to manage now that the Community is an exporter of these same products: it is now paying huge refunds and receives very little from the variable levies. Some observers, such as Parodi and Chombart de Lauwe, conclude that the system of price supports has mostly benefited the large grain producers, instead of providing the smaller farmers with an "adequate income". This assertion, of course, is consistent with the evolution of farm size that was discussed earlier. But it is not clear whether price policies have encouraged or hindered this evolution,[9] since other factors (especially the French structural policies and the pressure of technical change) have interacted with these price policies.

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[8] There is also disagreement on the effects of the CAP on world price variability. Schiff estimated that between half and two-thirds of the wheat world price variability caused by trade restrictions is due to the EC. On the other hand, according to the EC commission, "the stabilizing machinery of the CAP also plays a very important role on the world market; this stability benefits not only Community producers but also suppliers, at least in normal times "(Commission of the EC, p.20). See Tangermann for a discussion of the effects of the CAP on world market stability.

[9] See III.2.1.1.2. for a presentation of some alternative scenarios.

II.4.2.2. The budget of the Community

The EC treaty states that "the revenue and expenditure shown in the budget shall be in balance". Because it directly flows from our previous discussion, the expenditure side will be examined first, and the resources next.

II.4.2.2.1. Expenditure

Most of the expenditure is a direct consequence of the EC treaty, and is therefore compulsory (the European parliament has no control over it). As table II.14 indicates, the most important item of compulsory expenditure is the one we are interested in, i.e., the section of FEOGA devoted to price support (also called the guarantee section of FEOGA). This section has rarely received less than 70 percent of the total budget, the lowering in 1981 being due to considerable payments to the U.K. (Harris *et al.*). Two products account for a substantial proportion of FEOGA expenditure: milk and cereals. In the late seventies and early eighties, the portion allocated to milk (and milk products) was some 30 percent of the total, and 16 percent went to cereals.

At its creation, the FEOGA was divided into two parts: the guarantee section , which we just discussed, and the guidance section aimed at structural reforms. The latter has never received the importance it was designed to have (Chombart de Lauwe), probably because of the rapid rise of expenditures by the guarantee section. As an indication, the FEOGA budget was split 83 and 17 percent respectively for the guarantee and guidance sections in 1971 (Chombart de Lauwe), while these percentages were 94 and 6 percent two years later (Parodi). They have remained at comparable levels since that time.

II.4.2.2.2. Resources

Table II.14. FEOGA Guarantee Section spending as a proportion of the total budget of the European Community

Year	Percent
1973	77.4
1974	67.3
1975	69.6
1976	71.4
1977	76.8
1978	70.8
1979	71.0
1980	70.2
1981	61.6

Source : Commission,
Vol 7, p.A/83, 1982.

The financing of the EC budget comes from two sources. First, since the beginning of 1971, all levies charged on agricultural imports from third countries have been credited to the budget of the Community (as well as customs duties charged on industrial products). Second, a value added taxation, VAT, is applied by the member states in a uniform manner, of which the Community's share is no more than one percent. This VAT will be replaced in the near future by national contributions based on total national GNP in relation to total Community GNP.

From year to year, the percentage share of the Community budget coming from agricultural levies, customs duties and the VAT vary, and so does the geographical distribution of receipts. Of note is the relatively small proportion of resources arising from agricultural levies (7.2 percent in 1983). That year, the sugar levies represented 4.7 percent, the customs duties 34.9 percent, and the VAT 53.3 percent (Harris *et al.*).

To close this section, consider briefly the costs and benefits of the CAP to member states, France especially. The question is to compare the actual situation with a set of national policies that would have the same impact on prices as the CAP, but without common funding or free trade between the members states. Table II.15 represents such a comparison. CAP transfers are made through the budget but, in addition, trade among the Community countries takes place at Community prices, not at world prices, which entails an additional benefit -- or cost to consumers. Note that table II.15 represents net transfers of member states to the CAP, so that a positive value is actually a cost to the country. France, as the main exporter of agricultural products, appears as one of the beneficiaries.

II.5. Summary

This chapter has given a brief description of the vigourous growth of the French economy since

Table II.15. Transfers to the EC budget induced by the CAP

(in million British pounds)

	CAP transfers through the budget	Estimate of trade transfers	Total
Belgium/Luxembourg	-49	+300	+250
Denmark	-336	-375	-710
West Germany	+465	+125	+590
France	-255	-600	-850
Ireland	-339	-275	-610
Italy	-4	+700	+700
Netherlands	-329	-325	-650
United Kingdom	+882	+225	+1110

Source : Calculations by the British Ministry of Agriculture, Fisheries and Food, following the methodology of Rollo and Warwick (1979). Published in House of Lords, Volume II, p.194, 1981.

the late fifties. The trends and issues identified present a striking similarity to the U.S. case.[10] The expansion of the agricultural sector cannot be understood apart from its relationship to the general economy through labor and capital markets. This is accentuated by the fact that the agricultural growth is characterized by a large labor migration towards the non-agricultural sectors and also by a rapid capitalization within agriculture. This rapid capitalization was favorized by a dynamic technical change due at least in part to a tremendous increase in public research expenditures. French credit and structural policies have helped shape the sector and have complemented European policies introduced through the CAP. The price support policies have used by far the largest part of the Community's budget, because of their open-ended nature. Structural policy has been left mostly to the individual member states. Determining the relative impacts on agricultural growth of all the forces mentioned above remains the question to be addressed.

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[10] See for example Cochrane (1958), Griliches (1963), and Cochrane and Ryan.

CHAPTER THREE

THEORETICAL ISSUES

III.1. Introduction

This chapter is divided into four main sections. The first three sections discuss the main theoretical issues pertaining to this study. Price policy is discussed first, with its effects on production through both high and stable prices. Then, technological change is addressed, and the relationships between agricultural research and technical change discussed. Technical change, in turn, is linked to factor transfers between agriculture and the rest of the economy. These factor transfers are discussed in the third section of this chapter. The last section reviews the main approaches of the economic growth literature .

III.2. The effects of price policy

It was mentioned earlier that the price policy of the EC was designed to guarantee adequate incomes for producers. Our interest is somewhat different, since we want to understand the relationships between price policy and output growth. This section explores the processes by which the price policy of the CAP has potentially affected output growth in the agricultural sector. The potential consequences of high and of stable prices that can be foreseen with economic theory are considered separately.

First, the effects of high prices are discussed. Prices can potentially (i) induce a transfer of resources into the sector and thus increase output, and (ii) improve farmers′ income which, in turn, may affect the adoption of improved technologies. Second, the discussion turns to the effects of price stability. Stable prices may potentially (i) improve farmers′ income, and (ii) increase farmers′ investment in existing or new technologies by making those investments less risky.

III.2.1. The effects of high prices

III.2.1.1. High prices and supply response

It is straightforward to show that a profit-maximizing farmer with fixed land, capital, and family labor faces a positively-sloped supply curve.[11] Thus, he reacts to an output price increase by increasing the quantity of output produced. Under broad conditions, it can be shown that the same conclusion holds for the agricultural sector as a whole. This can be seen by dividing the economy into an agricultural and a non-agricultural sector, each producing one composite commodity. By further assuming that both sectors use two factors of production, labor and capital, we have a two factor two commodity model.[12] When the price of one good, say the agricultural price, increases exogenously, everything else being constant, resources are transferred into agriculture, which leads to an increased agricultural production and a decreased non-agricultural production.

In that context, where an increase in the relative price of agricultural products leads to increased agricultural production, two problems must be addressed. First, it is difficult to determine to what

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[11] The aggregate supply function may have negative slope in the presence of external economies. See Henderson and Quandt, p.144.

[12] This type of model is frequent in trade theory. For simplicity, constant returns to scale production functions, perfectly mobile inputs, and perfect competition are usually assumed (see for example Chipman). Relaxation of these assumptions complicate the models without altering the main results. For example, see Jones, R.W., for a model allowing for fixed inputs in each sector.

extent prices have been historically high. Cochrane and Ryan, trying to estimate the magnitude of U.S. surplus farm production in the 1950s, used the logical concept of equilibrium price, i.e. the price at which supply equals demand. They found that, to eliminate the production surplus estimated at 7%, farm product prices would have needed to drop by over 20% at retail and by more than 40% at the farm level.

This poses the second problem, the existence of excess capacity in the agricultural sector of many developed countries. A possible explanation is found in a now famous theory of Cochrane (1958), by which he explained that the excess capacity in American farming grew out of four circumstances: (i) the high value placed by society on scientific research and technological development; (ii) the market organization within which farmers operate; (iii) the inelasticity of aggregate demand for food; and (iv) the inability of resources to shift easily out of farming.

These four components are inter-related. In part because of public support, new and improved technologies are available to farmers. Farmers adopt those technologies eagerly because they operate in a "perfect" market, where they take price as given. Unable to influence price, lowering their costs is the only way they can increase profits. This leads to adoption of new cost-reducing technologies, which increases output in the aggregate. Demand being extremely inelastic, the excess production requires a large drop in price to be absorbed by the market. This price drop is exacerbated by the inelasticity of aggregate farm product supply. If supply were elastic, when price drops productive resources would be quickly moved from agriculture to other sectors, and a bottom would be placed on the price decline. But, Cochrane explained, resources cannot easily move out of agriculture so excess production remains and prices are driven down further[13]. Since in Europe, as in the U.S., farm income has been a sensitive political issue, governments have not been willing to let prices fall, and have intervened in various ways to support agricultural prices, thus creating what Cochrane calls chronic surpluses.

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[13] This, of course, takes asset fixity in agriculture as a fact. This has been questioned by Chambers and Vasavada, who rejected the presence of fixities involving labor, capital, or materials in U.S. agriculture.

The key issue, then, is to determine the relative proportion of growth in agricultural production due to movement along the supply curve as compared to outward shifts of the supply curve brought about mainly by technical change. It is clear that these two explanations are inter-related. Both increase output. To get the net effect over time of price policies, it is important to determine whether or not high prices improve farmers' income, putting them in a better position to invest and adopt new technologies. It is also necessary to examine the relationships between stable prices on the one hand, and farmers' income and risk attitudes on the other. These issues are discussed next.

III.2.1.2. High prices and farmers' income

Economic theory prompted Cochrane to argue that no price support program can increase the income of the average farmer in the long-run if he is placed in an atomistic competitive market. In fact, it can be easily deduced from the assumptions of perfect competition that the representative farmer earns a return just sufficient to keep him in business, no matter what happens to the price level. If, for example, price increases as a result of market forces (or of price policy), all farmers will seek to expand output. Output price will fall or input costs (including land rentals) will rise to the point where profits are eliminated.

Cochrane showed that this result of zero long-run profits still holds when the price is supported by a governmental action. In that case, farmers again will seek to increase output. But now, the price does not fall as output increases, since the government (for example, the EC) supports the price with no quantity limitations. In the short-run, all farmers earn higher incomes. In this situation, Cochrane explained that farmers begin to compete with one another for the limiting resource, typically land, to further increase output. This competitive process bids up land values, and costs of production increase again to a level such that the representative farmer earns a return just sufficient to keep him in business. This characterizes the treadmill effect popularized by Cochrane.

Recently, Cochrane (1986) has argued that the bidding up of land values does not occur immediately. Early adopters of technological advances see their profit position maintained in the short-run, and therefore seek to expand their farming operation and increase their total profits. They do this by bidding land away from the less aggressive farmers. Thus, in Cochrane's view, a combination of price support programs and technical change favorizes the concentration of land in fewer and fewer hands. However, the opposite argument can also be made. By postponing the price squeeze mentioned above, price supports allow inefficient farmers to stay on the farm. It is true that any available land will be bid away by the more progressive farmers, but nothing forces the small (or inefficient) farmers to put their land on the market as long as their profit is maintained at a minimum.

It is unclear, at this point, how much of the increase of output over time can be attributed to high prices. According to Cochrane (1958), price support programs had a greater impact on output growth in the U.S. because they stabilized prices than because they raised them.

III.2.2. The effects of stable prices

Price stabilization has been the subject of an enormous amount of study, and the discussion here is selective. The problem of measuring price instability was explained by Danin, who proposed an index to be used for comparative purposes. The question of what is to be stabilized from a welfare maximization standpoint -- prices, quantities consumed, or quantities produced -- was addressed by Subotnik and Houck. The bulk of the literature deals with the desirability of price stabilization and the controversial question of who benefits and who loses from stabilization. Studies that examine consumers benefits (such as Waugh, 1944 and 1966, or Samuelson), that compare welfare gains of producers and consumers (such as Massell, or Turnovsky), or that discuss the effects of price support programs on the distribution of income within agriculture (such as Robinson, 1965) are tangenital to the current study and are not reviewed here.[14]

The potential effects of stable prices on output growth are central to the problem in this study. Stable prices can potentially affect output growth through two different channels. Stable prices can induce farmers to invest more by (i) increasing their average income, and/or (ii) providing a more secure economic environment. These two aspects are examined next.

III.2.2.1. Stable prices and farmers revenue

Price stabilization and income stabilization are two related -- but distinct -- topics. Income stabilization has received a considerable amount of interest because, in Tweeten's words, "the major long-term problem of commercial farms is not labor mobility, low resource returns or low income but rather its instability". Our interest here is not income instability per se,[15] but the relationships between price variability (or stability) and average income.

In an article that spurred much debate, Oi challenged the view -- that he called intuitive -- that a competitive firm should always prefer stability to instability in prices. He concluded that, given a fixed expected price, the greater the variability about that expected value, the greater will be the expected profit. Risk-neutral producers thus prefer price variability to price stability. The only assumptions required were -- in Oi's words -- that "firms maximize short-run profits during each period", and that "the marginal cost curve of each firm is upward sloping throughout the relevant range". Oi also assumed that all producer decisions are executed after the actual price is revealed.

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[14] For a review of the literature on price stabilization, see Schmitz, Andrew.

[15] Sources of income instability have been traced to domestic macroeconomic policies by Schultz, to exchange rates by Schuh, and to each of those and farm output by Firch.

Tisdell criticized Oi's assumption that all decisions are made ex-post and instead assumed that all producer decisions are made before the actual price is observed. He argued that Oi's conclusion is correct only if one assumes perfect knowledge or complete mobility of factors. Tisdell showed that a situation in which producers are completely uncertain of the pattern in which two equally probable prices will occur does not lead to greater average profits than if price remains at the average value. He concluded that risk-neutral producers are indifferent between price variability and price stability.

Hartman, and more recently Hiebert, went beyond Tisdell's result of non-strict preference. Both used a simple one-output two-input model, where one input can be chosen after price is observed -- and is in that sense variable -- while the other must be chosen before price is known -- and can thus be viewed as fixed. Both had similar conclusions, mainly that risk-neutral producers may strictly prefer price variability, but that no generalization can be made. In their models, two antagonist forces affect producers income. Hiebert explains that, in the presence of a fixed input, output price variability imposes a penalty on the producer because of the chance that the firm will be using a sub-optimal amount of the fixed input, given the realized value of price. This penalty -- i.e. what turns out to be a poor decision regarding the "fixed" input -- can offset completely the advantage (pointed out by Oi) of price variability, resulting from adjustments in the variable input after price is observed. Hartman believes that, in many cases, the former effect dominates, making price stability preferred by risk-neutral producers.

In another study, Herrmann and Schmitz developed a theoretical model comparing the sources of income variability in European agriculture under free trade and with the CAP. Under free trade, income variability is created both by supply instability and demand instability, both domestic and foreign. With the CAP, variable import levies and/or variable exports restitutions completely absorb foreign supply and demand fluctuations (see II.4.2.1), and transmit domestic supply and demand fluctuations to the world market so that domestic price therefore remains fairly constant. Fluctuations of domestic supply are then the only source of revenue fluctuations. This does not mean, however, that the CAP stabilizes revenue. In fact, under free trade and various sources of instability, revenue can be relatively stable. This can be due to opposite price and quantity fluctuations or negatively correlated stochastic disturbances (Herrmann and Schmitz). Also, Newbery and Stiglitz point out that individual options for reducing revenue risks can be applied by the farmer in a perfectly competitive environment. These include diversification of production, crop storage, and hedging on the futures markets. With the CAP, incentives to hold private domestic stocks and to engage in futures markets activities are almost eliminated, and markets for sharing and reducing risks become thinner or disappear completely (Schmitz, P.M.). The incentives for diversification are also reduced, so that stable prices should have an effect on the structure, if not on the level of production. Therefore, whether the CAP stabilizes or destabilizes domestic revenue depends on the relative weights of reductions of instability-generating and instability-absorbing elements.

Herrmann and Schmitz suggest another argument to support their assumption that price stabilization does not always lead to revenue stabilization. Policy risks may substitute for market risks due to the annual price decisions of the EC and due to adjustments of external trade regulations as well as internal market regulations. Market prices may move between EC intervention and EC threshold prices (see figure II.1) caused only by policy decisions and without a significant linkage to supply risks. On the other hand, supply and trade movements are more closely and negatively correlated under free market conditions. Herrmann and Schmitz conclude that, under CAP conditions, the price risk and the supply risk are more or less cumulative with respect to revenue risk, whereas under free trade the supply and price risks tend to compensate each other.

Furthermore, if producers are risk-averse, they will adjust their chosen production and risk reducing techniques to trade-off between mean income and risk. The reduction in risk consequent upon a price stabilization program thus will lead them to choose riskier techniques. The amount of variability which the authorities will have to absorb will then increase along with the cost (Newbery and Stiglitz).

III.2.2.2. Stable prices and agricultural investment

By assuring price stability, Cochrane and Ryan argue, government programs provide a price insurance that the more dynamic farmers use to expand their production. This stable environment induces these farmers -- alert and aggressive in Cochrane and Ryan's words -- to invest in new and improved technologies. Farmers are like other businessmen, tending to divest in periods of falling prices, wary of making investments in situations of uncertainty, and investing more heavily when the future is bright.

This hypothesis of causality from price stability to investment, and from investment to the adoption of technical change, is supported -- according to Cochrane and Ryan -- by the 50 percent increase of aggregate farm output in the U.S. between 1948 and 1973. During that time, in the authors words, "the climate involved stable but not high product prices, tolerable but not good income, but it protected the producer against a price collapse in the coming year". According to this view, the increase in agricultural output was not a response to higher prices along the supply curve, but rather resulted from a shifting of the highly inelastic short-run aggregate supply function. This shift occurred because the farmers "adopted new and improved technologies and invested in new and improved capital items" (Cochrane and Ryan). Price stability therefore accelerated the adoption of technical change. But how is that adoption taking place? What causes technical change to occur in the first place? These questions motivate the next section, where technical change is examined in more detail.

III.3. Technological Change

This section is comprised of two main parts. First, studies that evaluate the importance of research are reviewed. These studies treat research expenditures as exogenous, and typically estimate the returns to research. The various methods used are mentioned, and the main results presented. Second, the focus shifts to studies where technical change is endogenized. The emphasis, in these studies, has been the factors affecting the demand for research. The supply of research has received less attention in these attempts to endogenize technical change.

III.3.1. The returns to research

There are basically two types of studies that evaluate returns to research: ex post studies that estimate the returns to past -- or completed -- research, and ex ante studies that evaluate future research projects. This study is concerned with determining the role played by research in the rapid technological change that has permeated France's agriculture during the past thirty years, and thus the former approach is appropriate. This section focuses on ex post approaches, to the exclusion of ex ante studies.[16] It is divided in three parts. Basic approaches to ex post evaluation of returns to research will be presented first, with their limitations. Some methods used to avoid these limitations are the subject of two following parts.

[16] The interested reader will find a review of ex ante approaches in Norton and Davis.

III.3.1.1. Basic approaches

Methods used to estimate ex post returns to research are of two main types: the index number approach and the production function approach. Both methods are described by Norton and Davis, Schuh and Tollini, and others, and thus will only be summarized here.

The index number approach consists of calculating the value of inputs saved through more efficient production techniques compared to expenditures on research, extension, and education (although the latter two often are not included in the studies). Growth in agricultural productivity is usually defined by an index. In effect, what is estimated is the increase in consumer surplus resulting from the saving of inputs, so that these studies estimate average returns to research. The total input measure does not capture changes in input quality (White and Havlicek, 1982). Also, this approach does not allow one to determine the effects of research on the relative productivity of input categories (Norton and Davis).

The above restrictions make the production function approach better adapted to the problem in the current study. The general idea of that approach is that agricultural output depends on conventional inputs (land, labor, fertilizers, etc.) and also on non-conventional inputs, essentially research, extension, and education. Griliches (1964) was the first to use non-conventional inputs as separate variables in a production function. Since his early study, this approach has been used extensively (e.g. Evenson 1967, Bredahl and Peterson, White and Havlicek 1981, and Cline and Lu). These studies have used expenditures at land-grant universities and other institutions on agricultural research, education and extension as measures of the non-conventional inputs. Some researchers have disaggregated research and extension expenditures among commodity groups (Bredahl and Peterson), while others have been interested in aggregate output and have used total research and extension expenditures by several sources.[17] All the above studies thus use research expenditures as

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[17] Cline and Lu used expenditures from experiment stations, the USDA, and the Soil Conservation Service. White and Havlicek (1982) also used data on production-oriented expenditures from several federal

an explanatory variable. This is a limitation, since expenditures are a research input whereas what one would like to estimate is the effect of research output. Research expenditures are used because of the difficulty of measuring research output. A few studies have addressed this limitation by using the number of scientific publications as a proxy for research output (for example, Evenson 1974).

Most studies have been made at the national (U.S.) level, and often indicate high returns to a wide range of agricultural research and extension investments, while a few also consider education.[18] Griliches (1963) cautions that the high returns found in these studies may be overestimates, since input quality (such as quality of labor) needs to be explicitly accounted for. Otherwise, it is implicitly attributed to technical change.

The above studies estimated the domestic returns to U.S. research, and neglected technology transfers among countries. While it is true that domestic benefits are what policymakers are mostly concerned with, allowing for international trade allows one to address issues that otherwise are overlooked. Some studies, Akino and Hayami for example, assumed that the country in which research reduces costs is able to trade any quantity of the commodity without influencing world price. Others, like Martin and Havlicek, and Sarris and Schmitz, allowed for effects on world prices via an excess demand curve. In these studies, research is assumed to shift supply only in one country. Edwards and Freebairn developed a model in which research reduces costs both at home and abroad, although in a partial equilibrium context.

The latter three studies estimated the benefits abroad of research at home. In this study, the opposite will be relevant: to estimate the benefits at home of research abroad in order to analyze the sources of agricultural growth. Most of the literature on transfers of technology deals with transfers from the developed to the less developed countries, or from one region or U.S. state to

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agencies, as well as unpublished data from the Cooperative Extension Service for extension expenditures and from the Cooperative State Research Service for the state agricultural experiment stations' expenditures.

[18] For a summary of these results, see Peterson and Hayami, and Ruttan (1982).

another. The international agricultural research centers, designed in part to help transfer technology from the temperate to the tropical zone, represent one effort to facilitate this type of transfer.[19] Transfers of research between developed countries has not been studied extensively. Evenson and Binswanger explain that, in general, a country has three options to improve the productivity of a sector of its economy. It can (i) adopt techniques from other countries without altering them through research of its own; (ii) modify or redesign borrowed techniques to suit its own resource endowments; or (iii) screen scientific knowledge from other countries to produce its own techniques. Its seems likely that transfers between developed countries would be primarily of the two latter types, since these countries have the required infrastructures and because conditions are usually sufficiently different between countries that the first type of transfer is relatively ineffective.

The studies discussed thus far considered public research (and extension) directed primarily at improving biological, physical, or mechanical technologies. To complete an evaluation of returns to research, the contributions of social sciences, on the one hand, and of private research on the other also need to be considered.

Ruttan (1984) argues that the contribution of new or improved technologies to production is well enough understood, but such is not the case for the contribution of the social sciences. Some reasons for this lack of study are explained with reference to agricultural economics research by Norton and Schuh. The main output of agricultural economics research is information, which is very difficult to measure, since it is not imbedded in new or improved inputs. Norton proposed empirical means for conducting an evaluation of impacts of agricultural economics research. He concluded that measurement procedures are available, especially for research which provides management or price information. Evaluation of research which provides institutional information is more difficult due to the problems with establishing causality between the research and subsequent institutional change. Even so, the benefits of agricultural economics and other social

[19] For a description and an analysis of the international research centers, see Dalrymple, and Hayami and Ruttan p.264-279.

sciences research may be high. Ruttan, for example, suggests that "the lack of economic knowledge has at times imposed very heavy costs on American farmers and on the American economy".

The omission of private research affects evaluation of public research expenditures in a different manner than omission of social science research. The omission of private research can only bias upward the results of the above studies. This is because of interactions between public- and private-sector agricultural research, so that measuring only public research expenditures will understate true inputs. Ruttan (1982) explained that "a relatively large share of the new knowledge and new technology generated by public-sector research reaches the ultimate users as inputs -- machines, materials, and services -- supplied by the private sector. A relatively small share is transferred or communicated directly to the users...without the private sector's participation". Research expenditures by private firms are not included in the above studies because they are very poorly documented and are hard to estimate. Part of the benefits of private research can be expected to be captured in the prices of the inputs (Norton, Coffey and Frye).

Finally, many of the above studies used a Cobb-Douglas specification. These functions are easy to estimate (linear in logs), allow one to compute marginal products very easily, and require estimation of relatively few parameters. But, the Cobb-Douglas production function is a restrictive formulation that assumes separability and unitary elasticities of substitution among inputs (Lyu, White, and Lu). Such restrictions can be avoided by using flexible functional forms (Ray). For example, Lyu, White, and Lu estimated both Cobb-Douglas and translog functional forms, and concluded that the use of Cobb-Douglas would overestimate the internal rate of return of agricultural research and extension expenditures.

Some studies (Huffman and Evenson, Norton) have used flexible functional forms but in conjunction with a profit function as opposed to a production function approach. The following section explains this dual approach in more detail.

III.3.1.2. The dual (profit or cost function) approach

There are several problems associated with aggregate production function estimation. One theoretical problem is that the function may be subject to simultaneous equations bias, in the sense that some of the variables that are assumed to be exogenous are in fact simultaneously determined with output. Other problems are the difficulty of disaggregating output and of deriving input demand functions when flexible forms are specified for the production function. The dual approach facilitates disaggregation of outputs, allows one to easily obtain input demands even from flexible forms, and, in some cases, reduces the problem of simultaneous equations bias inherent in many production function analyses. Binswanger (1975) explained that there is a one-to-one correspondence between production and profit (or cost) functions. Estimating a profit function provides the same information as would direct production function estimation. An example of the theory and application of this dual approach is given by Sidhu and Baanante and by Huffman and Evenson who estimated profit function models for U.S. agriculture.

Duality theory has been utilized in aggregate studies of agricultural technology by several authors, using various specifications of profit or cost functions. Translog profit functions were estimated by Weaver (1983) and by Antle. Weaver concentrated his study on the U.S. wheat region, and found decreasing returns to size and biased technological change. Antle used aggregate data from 1910 to 1978, and found that technological change biases have been consistent with relative price trends both before and after the war.[20] Translog cost functions were estimated by Binswanger (1974), by Kako, and by Ray. Binswanger compared technology induced biases between several regions of the U.S. using data from 39 states and four different years. He found that technical change had been equally labor saving in all regions, and inequally land saving and fertilizer using among regions. Kako decomposed changes in derived factor demands into three separate components: output level, factor substitution effects, and technical change. He found the

[20] The relationship between price and technical change is taken up in the following section on induced innovation theory.

decline in labor input level to be due mainly to technical change. Ray disaggregated output between crops and livestock, and found a 1.8 percent yearly rate of technical change in the U.S. over his period of study (1939-1977). Lopez (1980) estimated a generalized Leontief cost function to derive a system of four input demand equations (labor, capital, land, intermediate inputs). He concluded that "the observed reduction in the labor/capital ratio may be due to relative price and output expansion rather than to (biased) technological progress".

Other dual studies concentrated on the state level. Shumway, for example, examined the structure of technology in agricultural production for six Texas field crops. He wanted to determine whether individual products were independent of production decisions about other outputs, and if products could be consistently aggregated. He concluded that only wheat production decisions can be modeled indepently of decisions on any other major Texas field crop, and that consistent aggregation was possible only for three of the crops (cotton, sorghum, and corn). Evenson (1981) and Huffman and Evenson estimated profit, output supply, and input demand functions including research, extension, and teaching variables as fixed factors. While Evenson concentrated on the theory, Huffman and Evenson found that "research, extension, and farmers′ schooling are significant sources of productivity increases".

The dual approach has thus been used successfully to evaluate impacts of research. Two problems faced in almost all empirical work are estimation of the research lag and multicollinearity. These problems are discussed in the following section.

III.3.1.3. Distributed lags and multicollinearity

The problems of estimating the research lag and of multicollinearity are not independent. The first one is a specification problem and the second an estimation problem.

The first problem arises because of the fact that research and extension expenditures in one year may affect productivity over several years. Many studies agree (in some cases implicitly) with Evenson's original empirical assumption in 1967 that the lag structure of agricultural research resembles an inverted V. There is an initial lag between research expenditures and research output, after which the impact of research increases over time as more and more users adopt research results. Eventually, this impact decreases as research results both depreciate and become obsolete.[21] Evenson (1967) specified an inverted lag with data on U.S. agriculture and found a research lag of 12 to 15 years, with the stronger effect (the high point of the inverted V) occurring around 6 to 7 years after the actual expenditures.

Cline and Lu also estimated an aggregate production function for U.S. agriculture. Research expenditures were included by using a polynomial distributed lag, with lag lengths varying from 7 to 17 years and the polynomial degree from 2 to 4. The 13 year second-degree polynomial provided the best fit. To test whether or not research returns eventually decline to zero, Cline and Lu estimated their models with lag weights constrained to decline to zero (closed end-point constraint) or non-constrained (no end-point constraint). In their best model, they could not reject the closed end-point assumption. Most subsequent authors have imposed a closed end-point specification. For example, White and Havlicek (1981) used a second-order polynomial lag structure with closed end-points, to analyze research and extension impacts in U.S. agriculture. Their best fit was obtained with an 11 year lag for research and extension combined.

The returns to extension and teaching have not been estimated to the same extent as the returns to research. Norton, Coffey and Frye pointed out that extension would logically have a shorter lag than research, and education a longer lag. Some of the benefits of the latter involve problem solving knowledge which depreciates very slowly. They estimated rates of return, with benefits spread over 12 years for research, 9 years for extension, and 16 years for education.

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[21] This implies that a "non-negligible rate of investment in research may be required just to keep us where we are and to prevent us from slipping back" (Griliches 1973).

Empirical results show that there is a period during which research impacts at an increasing rate. There is disagreement on the rate and length of depreciation. Swallow *et al.* present empirical results showing that, when no final end-point constraint is imposed, very little depreciation occurs during the first 12 years. The authors reject the null hypothesis that the final end-point constraint is valid, in contrast with Cline and Lu. Cline and Lu had not made any correction for multicollinearity, whereas Swallow *et al.* did. With the large number of lagged variables used in these estimations, multicollinearity is virtually certain to be a problem. Let us now turn to this problem of multicollinearity.

White and Havlicek (1982) argue that measuring the separate influences of extension and research on agricultural productivity is always difficult because of the high multicollinearity between these variables in time-series data. They combined research and extension in their analysis. Nevertheless, several techniques allow one to considerably reduce the pervasive effects of multicollinearity.[22] Mittelhammer *et al.* used three alternative regression techniques to reduce multicollinearity. Two of the methods require prior information on the form of linear constraints on the parameters of the model, which make them hard to use. The third one -- principal components -- markedly improved the precision and theoretical reasonableness of the estimated parameters. Principal components is explained verbally by Mittelhammer *et al.*, and mathematically by Johnston (p.322-331).[23] Another method -- ridge regression -- is explained by Brown and Beattie who used it in a simple regression problem.[24] Norton, Coffey and Frye used both methods to estimate returns to agricultural research, extension and teaching. They gave an example of the use of ridge regression, obtaining better results with the latter than with principal components regression. The authors pointed out that this is by no means a general rule and the best method to use depends on the particular data set.

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[22] For an explanation of the consequences of multicollinearity, see Johnston, p.159-168, or Montgomery and Peck, p.291-296.

[23] See also Montgomery and Peck, p.334-339.

[24] For a complete exposition on ridge regression, see Montgomery and Peck, p.310-327.

This concludes our brief discussion on evaluation of returns to research, extension, and education. In all the studies reviewed above, technical change is exogenous, i.e. taken as given by the researcher. A further step is to endogenize technical change and that is the topic of the next section.

III.3.2. Endogenizing research and technical change

Several studies have attempted to endogenize the demand for technical change. The major approach used has been the much debated induced innovation theory. This theory is presented first followed by a discussion of the financing of agricultural research. The influence of farmers' desires on the priorities and directions of research is discussed.

III.3.2.1. Induced innovation theory

The hypothesis of induced innovation was first introduced by Hicks, in his now famous Theory of Wages. To summarize the theory, changes in relative factor prices (caused by changes in relative factor scarcities) induce firms -- or farms -- to seek out innovations that would save the progressively more expensive factors, thus inducing biased technical change. Historically, Hicks argued, rising wages could be expected to induce entrepreneurs to demand labor saving innovations in order to offset rising labor costs.[25]

Among the many tests of the induced innovation hypothesis, two are particularly relevant for this study. The first one was developed by Binswanger (1978c). Although most of the tests found in the literature are two-factor tests, Binswanger's model allows for a more general perspective.

[25] For a good summary of the evolution of thought around the induced innovation concept, see Binswanger (1978a), and Hayami and Ruttan, ch.4.

He considered five factors: land, labor, machinery, fertilizer, and other inputs, and set up a multi-factor test that incorporates the measurement of factor-using bias for all five factors. He applied his test to U.S. agriculture for the period 1912-1968. His main result was that very strong price-induced biases in technology affected the use of fertilizer and labor.

A second relevant study is that of Ruttan *et al.*. They used time-series data from 1880 to 1970 to test the induced innovation hypothesis for the agricultural sectors of Japan, Germany, Denmark, France, the U.K. and the U.S. The authors concluded that each of the countries they examined has developed along a technological path that has been consistent with the country's particular resource endowments, and responsive to changes in relative factor prices within the country over time. A limitation of their empirical test is that it involves substitution between only labor and land, and is therefore not as general as Binswanger's. Also, the authors observed that differences in the rates of growth in demand for agricultural products may have played a significant role in inducing differential rates of technical change. Because of this observation, Ruttan *et al.* suggested that a test of the induced innovation hypothesis should be extended to include the effects of differential rates of growth in product demand (as reflected in output prices) in addition to the effects of changing factor prices. Consideration of the influence of the growth in product demand on the rate of technical change is not new in the literature. Because of the early contributions of Griliches and Schmookler,[26] Hayami and Ruttan refer to this approach to induced innovation as to the Schmookler-Griliches tradition. This approach views product demand as the main pull for the flow of innovations.

Changes in product demand and changes in relative factor prices are related, and both may influence the demand for technological change. The inter-relationships of product demand and factor prices are illustrated by an example borrowed from Hayami and Ruttan. Suppose that population, or per capita income, increases. This creates an increased demand for food, and an

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[26] See for example Griliches (1957) and Schmookler.

induced increased demand for factor inputs. Since all factors probably do not have the same supply elasticities, these increased factor demands create changes in relative factor prices. Those, in turn, are reflected in changes in the level of income and in income distribution among factor owners, which then results in changes in aggregate product demand.

An attempt to develop a model taking these interactions into account has been made by Ben-Zion and Ruttan. Their model concentrated on the effects of the rate of growth in aggregate demand on the rate of technical change, the latter being defined as the residual -- the change in output that is not explained by changes in labor and capital inputs. The authors found that, in the U.S. between 1929 and 1969, the rate of technical change did respond to changes in the rate of growth in demand with a lag of 3 to 7 years.

Even closer to the ideas of Hayami and Ruttan expressed above is an induced innovation model developed by Binswanger (1978b and 1978d). His model focuses on the firm and is based on the neo-classical profit maximization assumption. It includes the effects of factor prices, scale of operation, interest rates, product demand, and of exogenous advances in basic and applied knowledge on the amount and direction of scientific and technical effort of the firm. In particular, an increase in product price increases the marginal value product of resources devoted to research, and thus increases the optimal level of research expenditure.

Applying such a model of induced innovation -- developed at the firm level -- to the case of agriculture requires a crucial link. In fact, such a model explains how farmers are induced, by shifts in relative prices and by increases in product demand, to search for technical alternatives that save the increasingly more expensive factors of production. If there are effective interactions between farmers and research institutions, then the research demand from farmers will be addressed by the research sector. Technological change would then truly be guided by market signals, i.e. relative factor prices and final product demand. It is crucial to understand the link between farmers and agricultural research institutions, to find out to what degree the direction of research is influenced by the farmers. Thus, the source of financing of agricultural research turns out to be important. The next section presents the main conclusions reached by the literature pertaining to that topic.

III.3.2.2. Research financing

We noted earlier that an important part of agricultural research in France is publicly funded. The question then arises as to where the funding decisions are made in the national political system, i.e. what proportion of the research institutions′ budget comes from local funds and what proportion from national budget appropriations.

Guttman, and Huffman and Miranowski hypothesized that state spending on research and extension in the U.S. is influenced by the political effectiveness of two groups, farmers and producers of agricultural inputs. Guttman applied an economic model of political interest groups to the analysis of the demand for publicly financed agricultural research. He found that "the regression coefficient of the number of largest farms increased, and that of the number of medium-sized farms decreased or stayed approximately constant, as the number of farms in the commodity class increased". Guttman concluded that "this result, while not always statistically significant, provides limited support for the model of interest groups, which predicts that political participation by the largest farms should increase relative to participation by the smallest farms as the overall number of farms increases". Guttman found that per capita research expenditures are related to:

1. The size distribution of farms (more returns for larger farms). This is supported by other studies. Just and Zilberman identify farm size as an important variable in explaining the adoption of new technology;
2. Borrowable research (from neighboring states having similar conditions);
3. The number of firms producing agricultural inputs;
4. Coop membership, which reflects the level of organization of farmers; and

5. The proportion of farmers owning their farms.

Guttman found that "the coefficient of this (last) variable is positive where state output of the commodity is relatively low (high elasticity of demand for the final product), and negative where state output is relatively high (low elasticity of demand)". If there is a high demand elasticity at the state level, producers' surplus would increase when technical change shifts out the supply curve. Since owner-farmers capture a larger share of the increase in producers' surplus than tenants farmers do, the former will tend to favor investment in agricultural research the most. Guttman then links farm output of the state in a given commodity to the state-level elasticity of demand. He reasons that "the larger the state farm output relative to the national or world total, the greater will be the effect on the market price of a change in state farm output".

Huffman and Miranowski explained per capita spending on agricultural research by estimating demand along the same lines as Guttman, but by adding to the analysis the supply of research. They view research supply as an important determinant of the real quantity of research. On the demand side, they obtained results similar to Guttman's concerning the effects of the land tenure status of farmers and the size distribution of farms. They added that the support of agricultural experiment station research by the operators of large farms declined if there was a large quantity of applied research available from similar subregions in other states. Huffman and Miranowski also concluded that the demand for agricultural experiment station research is positively related to the quantity of agricultural output in a state. They pointed out that the elasticity of research expenditures with respect to output is reduced (increased) as a state's agricultural commodities become more concentrated (diverse), which supports the hypothesis of commodity specificity of research.[27] Another interesting conclusion of the study is that farmers in states with high farm wage rates demand more research expenditures, possibly to reduce the rising relative labor costs of

[27] Huffman and Miranowski explain that the expected returns from agricultural research are such that the marginal effect of a dollar of product output on the demand for research diminishes as output increases. Consequently, the authors expect the number of commodities produced indigenously to increase the aggregate demand for indigenous applied research.

agricultural production. The conclusions of the study on the determinants of research supply are discussed below.

In their study, Rose-Ackerman and Evenson confirm some of the above conclusions, i.e. that state demand for research and extension is influenced by the political effectiveness of farm interests and by the possibility of transfering technology from the neighboring regions. They add to the analysis the effect of the availability of federal grants and study specifically the effect of reapportionment of state legislatures mandated by the Supreme Court in 1962. Their results need not be presented here, because of their U.S. specific nature, except for the general conclusion that demand for research depends on political as well as on economic factors.

Some attempts have also been made to endogenize the level of expenditures for agricultural extension by itself. For example, Huffman and McNulty explained the allocation of local public agricultural extension by variables representing the average wealth position and membership size of farm and nonfarm pressure groups. The authors also found a strong negative relationship between farmers' schooling and the provision of county agricultural extension, which "suggests that they are substitutes in agricultural production".

This section has emphasized the fact that demand for research affects the level of research funding. But there are supply side factors as well, such as the availability of funds in the economy, itself dependent on the growth of the economy, the tax structure, the political will to prioritize public expenditures among other sectors, and so on. Other factors have also been identified in the literature. In a study already mentioned, Huffman and Miranowski found that expenditures for research are positively related to the budgeted share of staff research time and to the number of research centers per farm, and negatively (but not significantly) related to agricultural Ph.D.'s earned per full-time equivalent station researcher. Rose-Ackerman and Evenson pointed out, however, that these supply-side results have to be taken with caution because of measurement and causation questions. For example, it is not clear if a higher budgeted share of staff research time induces a high level of spending, or if a high level of spending enables research centers to budget a high share for research.

III.4. Interactions with the rest of the economy

It is an accepted view in the literature that "the interactions between agriculture and nonagriculture change significantly over time in the process of development" (Yotopoulos and Nugent, 1976a). Nevertheless, much of the literature dealing with these interactions focuses only on less developed countries. Such economies are characterized by predominant agricultural sectors, whose relative importance decreases as development takes place. In the early stages, agriculture provides a surplus of capital and labor while the terms of trade turn against it.[28] But, at latter stages, exchanges between agriculture and nonagriculture may differ considerably. This section is divided in two parts. The transfers of labor, and then of capital, that take place between agriculture and the rest of the economy in a developed country like France are discussed.

III.4.1. Labor transfers

As mentioned in the preceding chapter, labor migration from agriculture has been relatively steady in France over the past thirty years. Carré, Dubois and Malinvaud, and other authors have hypothesized that the rapid growth in the French economy has offered opportunities for employment, drawing people out of the agricultural sector. This would have occurred irrespective of technical change in agriculture. Thus, this hypothesis views structural change in the agricultural sector as a response to the growth in the rest of the economy. An understanding of the factors that

[28] This is the double developmental squeeze, introduced and developed by Owen.

have caused migration is, therefore, essential to sorting out the underlying causes of the growth of the French agricultural sector.

Migration from rural to urban areas has been studied extensively, principally in less developed countries. In these countries, population growth rates have been up to six times higher in urban than in rural areas, due to a massive exodus from rural areas (Yotopoulos and Nugent, 1976b). A series of studies -- beginning with a 1938 paper by Herbele -- analyze the forces which encourage an individual to leave one place and be attracted to another. The two most common approaches to analyzing migratory flows are regression and cost-benefit analysis.

Regression models essentially explain migration with a set of variables, which are ranked according to their predictive power. Lewis (p.106-116) reviews many of these studies. A limitation of these studies is their partial equilibrium approach. Rogers argues, for example, that "since the relationships between migration and development are multidimensional and complex, evaluations of their interactions call for a general equilibrium systems framework". Dualistic models of economic growth attempt to provide such a framework. In these models, the economy consists of a rural (agricultural) and an urban (non-agricultural) sector, and migration is usually analyzed in a cost-benefit framework.

The early literature viewed migration mainly as a response to wage differentials between urban and rural sectors (for example, see Jorgenson, Ranis and Fei, or Sjaastad). This is the basis of the human capital model, in which migration occurs as long as the difference between the present value of future urban wages and the present value of future rural wages (or income) plus migration costs is positive. This approach succeeds in explaining the direction of migration as well as some characteristics of migrants. For example, because they expect a longer time horizon over which to capitalize their earnings, migrants tend to be young. Education is also a factor, because the better educated expect to find higher paying jobs.[29] Although this approach provided some insights,[30] it has received a lot of criticism because it fails to explain why migration persists despite rising unemployment rates in urban areas.

This concern motivated Todaro (1969) to argue that the determinant of labor migration is not the real income differential, but rather the "expected" rural-urban income differential, which he specified as the income differential adjusted by the probability of finding a job. The chance that a worker will find a job, Todaro explained, is related to the size of the existing pool of the unemployed and the rate of employment creation. Costs associated with migration (moving expenses, loss of income while looking for a job, emotional stress, etc.) are also a part of the income differential. With his model, Todaro was able to explain how wage differentials could persist with unemployment remaining high, or even rising. The model has been used to evaluate short- and long-run policies to curtail the influx of rural migrants in less developed countries.[31] In particular, it was used to explain why purely "urban solutions" to the urban unemployment problem have tended to increase the pool of the urban unemployed, whereas "rural solutions" might help (Todaro 1971).[32]

Going beyond the dualistic approach, Yap (1976) estimated a three sector[33] neoclassical model, in which migration between rural and urban sectors was viewed as a means of equalizing factor returns. The model was estimated using 1950-1965 data for Brazil, and the impact on the growth of the economy was simulated. Among other results, she found that an exogenous reduction in

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29 This is not an exhaustive list of the description of migrants, which would be beyond our purpose. For good discussions of their characteristics, see Shaw, and De Jong and Fawcett.

30 See Yotopoulos and Nugent (1976b) for a more complete review of the application of the human capital model to migration in less developed countries.

31 See for example Harris and Todaro, Todaro 1971, or the review by Yotopoulos and Nugent, 1976b.

32 Some have criticized Todaro's model. See for example Peek.

33 One rural (agricultural) sector and two urban sectors, a productive (modern) sector and a less productive (traditional sector).

rural-urban migration would have increased the growth of agricultural output, decreased the growth of the industrial sector, and reduced the average annual growth of GNP.

The range of economic incentives to rural-urban migration includes more than income and employment opportunities. Better living conditions, better educational opportunities, or a wider variety of shopping, social and recreational activities may all be important motivating factors (Yap 1977). But Yap explained that these factors are difficult to take into account because of lack of data and econometric problems.

All the studies discussed so far have addressed migration problems for less developed countries. Nevertheless, they do have some relevance for France. In a study of the French population accross the 20th century, Dyer looked at the evolution of the population between the different sectors of activity (see table II.5). He concluded that "agricultural movements take place first for economic reasons". In another study, Pourcher examined the causes of migration to Paris. He found that migrants from agricultural origin moved primarily because farms were too small to offer a living or the work was too hard on the farm.

In a third study of rural exodus in France, Pitié presented the results of two questionnaires he distributed among several hundred people in the urban and rural areas of western France. People having migrated to towns overwhelmingly cited economic reasons for their move, such as insufficient income on the land, no security of income or income insufficient to raise a family. The only reason not directly mentioning farm income was "to marry". Among the people questioned, very few (2 percent) envisaged returning someday to farming. Seventy-four percent of the people questioned on the farm thought that those who had moved had obtained a better life, and fifty-two percent said they would leave if they could. Why they thought they could not leave was not reported. However, this implies the existence of migration costs, although they may be hard to estimate. Their implication is that labor in French agriculture may not be in equilibrium in the short run. As discussed later, the potential presence of adjustment costs in the labor (and capital) market is a critical aspect of the agricultural sectors of developed countries such as France and the U.S..

Among the studies that are not reported here are some aimed at predicting the response of migration to specific policy actions. Because these are primarily micro-economic studies in less developed countries, their specificity reduces their relevance to this study.[34]

Finally, Robinson (1965) observes that studies of factors affecting out-migration from agriculture generally conclude that the level of farm-product prices has less influence on decisions to quit farming than the availability of non-farm jobs and the age of the operator. But, in Robinson's opinion, "one would expect that the incentive to leave would be greater if farm prices were lower". To the best of our knowledge, the relationship between agricultural prices and migration has not been studied.

III.4.2. Capital transfers

A striking feature of the dualistic models mentioned above is the "complete intersectoral immobility of capital" (Jones, D.W.). In fact, in the Harris-Todaro model, capital is fixed in each sector, and can be neither shifted between sectors nor un- or over-employed in the sector to which it is assigned. This, explains Jones, is characteristic of a short-run analysis. Zarembka also develops a dualistic theory of development, but omits capital in the agricultural production function. Capital transfers then become a moot point, but such a model can be attacked on grounds of realism (Jones).

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[34] Yap (1977) presented a critical review of these studies.

Others, however, have developed models allowing for capital mobility. Kelley, Williamson and Cheetham developed a dual model of a growing economy, with two sectors (agriculture and industry), two factors (labor and capital), and exogenous technical change. In their model, capital and labor are assumed to adjust instantaneously to any price differential between sectors. Their analysis is thus developed in a long-run framework, where all inputs are perfectly variable.

Another example is given by Stoeckel (1979), who developed a five-sector general equilibrium model of the Australian economy. He assumed competitive conditions, which insures full employment of factors of production, labor and capital. Investment was treated as exogenous. Labor and capital were perfectly mobile between sectors, except for some fixed capital specific to the mining sector. Thus, for the most part, this is also a long-run analysis.

This concept is pushed one-step further by Mundlak, in his two-sector model of Japan. In this model, there is an essential difference between labor and capital flows. Although the entire labor force of a particular sector is considered movable within a given period, a good portion of the capital is sector specific. The allocation of capital is made primarily with respect to new investment, so that the most that can be invested during any given year is the gross savings of the economy for that year. The repartition of those gross savings between the two sectors depends on their expected rates of return. Capital flows out of agriculture during the development process because there are higher capital returns in the nonagricultural sector. If the productivity of capital is constant, Mundlak concludes, the flow of savings tends to equalize returns in the two sectors, and eventually this flow will diminish. Mundlak points out that this flow of capital is not independent of the concomitant flow of labor, but that they affect each other. Thus, although labor is still considered a perfectly variable input -- which is not very realistic in view of the discussion held earlier on labor migration -- some capital fixity is introduced in the model.

In Mundlak's model, the agricultural and non-agricultural sectors each generate savings that can be invested in either sector. In a later study, Cavallo and Mundlak use a different assumption. In their model, "investment in agriculture consists of products of agriculture, such as livestock and land improvements, and products of nonagriculture, such as machines. The investment in nonagriculture is assumed to originate solely in nonagriculture". From that assumption, Cavallo and Mundlak concluded that the production of investment goods by nonagriculture is determined by the demand for such goods generated in that sector and by the demand from agriculture. The authors again make the assumption that investment is the only mode for allocation of capital. In addition, they assume that the allocation of total investment between the two sectors depends upon the expected differential rates of return in the two sectors. Labor is still viewed as perfectly variable.

This concludes the discussion of the literature concerning the issues identified in chapter II as critical to our study of growth in French agriculture. Agricultural policy, particularly price policy, technical change in agriculture, and factor transfers between agriculture and the rest of the economy have been covered successively. In the remaining chapters of this study, we develop a profit function model of French agriculture and use the model to evaluate the relative importanct of the various sources of growth in French agriculture. The model we develop is a disaggregated sectoral profit function model (four outputs, three variable inputs, three quasi-fixed or fixed inputs) in the tradition of duality models used in the studies of returns to agricultural research cited above in section III.3.1.2. Before turning to our model, we examine our approach relative to other possibilities by comparing it to two broad alternatives in the economic growth literature.

III.5. Economic growth literature

Explaining the determinants of economic growth has long been an important and controversial issue among economists. A great deal of work has accumulated on the subject, encompassing such different approaches as those of Adam and the classicists, Marx, and more recently the neo-Keynesian and neoclassical economists. These theories have been reviewed and explained by many authors[35], and are not repeated here. Regardless of the theory used, and of its associated hypotheses, the intersectoral aspect of growth is widely accepted, and often leads to general equilibrium specifications. Before going into more details about the general equilibrium methodology, it is appropriate to examine the major approach found in the literature to quantify sources of growth, known as the "sources-of-growth" methodology.

III.5.1. Sources-of-growth methodology

This particular approach consists in performing an accounting decomposition of input growth that must totally account for, but not necessarily explain, output growth. It relies on the neoclassical assumption of an aggregate production function, and focuses on a supply explanation of economic growth. The amount of literature on growth accounting is enormous, and we will not attempt to review it. Rather, we will present the general approach, the insights that can be gained from it, and its limitations.

The main initial contributions to this body of literature are by Solow, Denison, and Jorgenson and Griliches. All three started with a production function: $Y = f(K,L,t)$, where Y is output, K is capital stock, L is labor force, and t (time) represents technical change and signifies that the relationship between inputs and output is changing over time. By differenciating Y with respect to time, we obtain the following expression:

$$g_Y = \mathrm{B}_K\, g_K + \mathrm{B}_L\, g_L + \alpha,$$

where g_Y, g_K, and g_L are the rates of growth respectively of output, capital, and labor, B_K and B_L are the elasticities of output respectively with respect to capital and labor, and alpha is the rate of

[35] See for example Choi.

technical change.[36] Note that, in perfect competition, the elasticities of output with respect to inputs are equal to the corresponding factor shares. The contribution of capital and labor can then be computed, the residual being α, the contribution of technical change.

The first studies indicated very high rates of technical change. Input growth usually accounted for less than half of the total output growth. Capital's contribution was surprisingly low, which was "due to the failure in the formulation to allow for the fact that an acceleration in the rate of investment brings with it an acceleration in the rate at which the efficiency of the capital stock increases... Technical change is not assumed to be embodied in new investments" (Choi, p.53). Another criticism was made by Jorgenson and Griliches (1967, 1972). They argued that the high residuals obtained by most authors were due to poor measurements of the labor and capital inputs. By adjusting for improvements in input quality and pointing out that capital flows, not capital stock, should enter the production function, the authors were able to explain most of the growth in U.S. national income by growth in factor inputs, the residual becoming very small. Their formulation maintained the usual assumptions of perfect competition, constant returns to scale production function, equality of factor-price ratios to their ratio of marginal productivity, and equality of marginal rates of substitution of goods to their prices.

Despite the limitations inherent to the above assumptions, the sources-of-growth literature provides a first approximation of the factors accounting for growth[37]. Nevertheless, as pointed out by Choi, decomposing total factor productivity into various components is not the same as explaining it. The causal relationships that link a particular factor to the growth rate cannot be examined with this approach. In a sectoral study like ours, the approach does not allow one to evaluate the determinants of resource allocation and cannot accomodate any input fixity

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36 This is the basic equation. Labor and capital have often been disaggregated to account of various qualities of labor and types of capital. For example, see Denison and Chung.

37 Some authors used this method as a first step, before constructing more complicated models. For a recent example, see Elias.

characteristics of the sector. The progress that can be expected by this approach toward an understanding of the sources of growth in French agriculture is therefore limited.

III.5.2. General equilibrium approach

General equilibrium models have been developed to model situations where many agents independently maximize their own welfare functions and jointly but inadvertently determine an outcome that can be affected only indirectly by the policymakers. These models generally incorporate links among several production sectors and the pattern of demand. In most economy-wide models, the production technology is described by a production function that allows smooth substitution among inputs. It is generally argued that "for most purposes in economy-wide modeling, the use of CES production functions with realistic substitution elasticities will capture most of the interactions one wants to analyze" (Dervis *et al.*, p.139). Of course, given the necessity of aggregating sectors into a relatively small number, production functions are only very rough representations of actual production processes.

Typically, general equilibrium models are solved simultaneously, usually by finding a set of prices and factor returns that equilibrates all markets[38]. Examples of this approach are numerous in the literature. With specific reference to agriculture, Stoeckel's five-sector model of the Australian economy was mentioned earlier. He assumed competitive conditions, which ensure full employment of factors of production, labor and capital. Prices adjust to maintain market equilibrium. Tower developed a model for a multi-sectoral open economy, in order to calculate the shadow prices of goods, factors, foreign exchange, taxes, tariffs, and quotas. He assumed perfectly flexible wages and prices, thus maintaining both full employment and balance of payments

[38] Instead of this price adjustment, models can be solved by quantity adjustment. For example, one objective may be to find an allocation of labor such that all labor is employed and marginal revenue products are equal across all sectors for the same labor category.

equilibrium. This type of model can be huge, as exemplified by the Basic Linked System developed by IIASA (see Frohberg), which is a system consisting of 20 detailed regional models comprising approximatively 80 percent of the world's total agricultural production. To solve the system, prices are endogenously calculated for the domestic and the world markets.

In choosing an approach to evaluate sources of growth in French agriculture, we gave considerable thought to a general equilibrium growth model. However, in the end we rejected the approach in favor of the sectoral profit function for several reasons. First, the above examples (many more could be given) point out the usual assumptions made in general equilibrium analysis, i.e., prices adjust until equilibrium occurs. This assumption (as well as the quantity adjustment assumption mentioned above) does not fit the French agricultural situation described earlier. Prices in the French agricultural sector cannot be viewed as equating supply and demand, since they are for a large part politically set. Labor and capital markets are characterized by adjustment lags, and are not in equilibrium in the short run. These factors could be taken into account by imposing additional constraints on the model. But, given the amount of details necessary to address the issues discussed previously, the model developed would quickly become very hard to manipulate. Second, to incorporate the entire ecomony one must aggregate severely across sectors or develop a very large model. Both approaches have their constraints. Instead, we choose in the study to treat the non-agricultural economy as exogenous and focus on modeling the agricultural sector in more detail than might otherwise have been possible. In this study, the agricultural sector is assumed to have no significant influence on the non-agricultural sector because of their relative sizes: agriculture has been responsible for around 5 percent of the French GNP over the period of study. The non-agricultural sector affects agriculture by determining the prices of the variable inputs and the opportunity costs for family labor and agricultural capital (non-farm wage and interest rate).

III.6. Summary

The discussion in this chapter illustrates that, to understand the growth of French agriculture, one needs to incorporate technical change, structural change, price policies, and the influence of the rest of the economy through transfers of resources, labor and capital. How to incorporate fixities in these markets is the topic of the next chapter.

The discussion in the next chapter leads to the choice of a profit function model to evaluate the relative importance of the various sources of growth in French agriculture. This model allows us to address many of the concerns that were identified in this chapter as relevant to that goal. Among these are: (1) the effects of price policies on output, variable input use and capital and family labor use in French agriculture; (2) the effects of French structural change and credit policies on both the level of resource utilization in agriculture and the level of agricultural output; (3) the role of technological change in the growth of French agricultural production over time; (4) the relative importance of French agricultural research and international technology transfers in overall technological growth in French agriculture; (5) the presence of adjustment costs in the labor and capital markets, causing these markets to be in disequilibrium in the short run; and (6) the impacts of these disequilibria on output growth, that involve comparisons between the short and the long run. Other concerns raised in this chapter are beyond the scope of our study. These include (1) endogenizing research demand and supply, (2) separating the effects of high prices and of stable prices on output growth, and (3) endogenizing the other sectors of the economy.

CHAPTER FOUR

MODELING INPUT FIXITIES

IV.1. Introduction

This chapter is divided into two main sections, in which the approaches designed to accommodate input adjustment costs in a multi-output framework are discussed. In line with the preceeding discussion, the dual approach to production modeling will be used in this thesis. Recall that this approach consists of specifying a profit (or cost) function, from which output supply and input demand functions are derived, without the need to specify a-priori the production function. Young et al. provide a good historical review of the development and use of duality theory. It is important to note that all inputs usually are assumed to be in static equilibrium in duality applications.[39] This is equivalent to assuming that all inputs instantaneously adjust to their equilibrium values, an assumption that does not necessarily seem appropriate in a study of agricultural growth. Rather the lack of mobility of self-employed farm labor and the possible fixity of capital assets in agriculture preclude full adjustment in the short-run. The long-run is defined as the period after which full adjustment is attained.

To accommodate adjustment lags for some inputs, two alternative approaches have been followed in the literature.[40] First, the firm can be assumed to be continuously in dynamic

[39] For example, Binswanger (1974) and Ray assume all inputs to be perfectly variable. Most other empirical studies distinguish between totally fixed and perfectly variable inputs, but restrict the analysis exclusively to the variable inputs. For some references on this latter approach, see section 3.2. of this chapter.

[40] A third approach consists of ignoring the problem by maintaining the assumption of full static equilibrium. This is done implicitly in most of the studies referred to earlier.

equilibrium rather than in static equilibrium. This approach uses dynamic programming and assumes that adjustment costs explain the short-run fixities exhibited by some inputs. Second, the firm can by assumed to be in static equilibrium with respect to a subset of inputs conditional on the observed levels of the remaining inputs. This approach is referred to as the variable profit function approach. The inputs that are in partial static equilibrium are called variable inputs, and the remaining inputs are designated as quasi-fixed. The theoretical foundations of both approaches can be found in Lau and in McFadden.

IV.2. Dynamic equilibrium

As mentioned above, the dynamic programming approach is based explicitly on dynamic economic optimization incorporating costs of adjustment for quasi-fixed factors. If no restrictions are imposed, this approach involves solving a stochastic dynamic programming model, the solution to which becomes difficult to obtain unless the model is kept to a few variables. To get around this problem, empirical applications have made use of various restrictive assumptions. In particular, the assumption of static price expectations is often made. This assumption results in the deterministic dynamic models referred to by Karp and Shumway, as opposed to the more general stochastic dynamic models. These two types of dynamic models are presented next, before a discussion of the cost-of-adjustment assumption that underlies all dynamic equilibrium models.

IV.2.1. Stochastic dynamic models

These models can be classified in two categories, according to the functional forms used and their underlying assumptions. Before presenting the approach in its more general form, the special case of linear quadratic models is discussed.

IV.2.1.1. Linear quadratic dynamic models

These models are built on the assumption that economic agents solve quadratic optimization problems, subject to linear constraints. This assumption allows one to obtain closed-form expressions for the equilibrium time paths of the quasi-fixed variables, and to solve these expressions for their optimal values. The procedure followed is explained by Karp and Shumway. Empirical applications include Hansen and Sargent, Kohn, and Wallis. This framework is based on very strong assumptions, "which may include linear technology and symmetric adjustment costs" (Karp and Shumway).

IV.2.1.2. General dynamic models

If the objective function is not assumed to be quadratic, Hansen and Singleton explain that obtaining closed-form solutions for the equilibrium time paths of the variables of interest becomes very difficult, if not impossible, and requires very strong assumptions.

To circumvent this problem, the same authors proposed a method that allows one to estimate parameters of a stochastic dynamic problem, without explicitly solving for the optimum values of the variables. The method consists of transforming the stochastic Euler equations (first-order conditions) into non-stochastic equations, by using an instrumental variables technique. The expectations in the Euler equation, at time t, are replaced by instruments which consist of variables observed at t. The resulting function is summed over t, and the quadratic form of this sum minimized with respect to the unknown parameters. The determination of the optimal weights is discussed by Hansen and Singleton.

Another advantage of a method that does not solve for the optimal rule is that it is consistent with duality theory. Recently, Taylor has shown that duality theory cannot be used to solve a maximization of expected value of profit if price expectations have a Markovian structure. A Markovian price expectation structure refers to any stochastic specification in which price is conditional on previous prices. Thus, Taylor's result is very general. Basically, the impossibility of deriving output supply and input demand functions from the expected present value of profits, with Markovian price expectations, occurs because "holding future prices constant when changing current price is meaningless in the Markovian problem" (Taylor p. 355). The approach proposed by Hansen and Singleton circumvents the need for explicitly deriving decision rules.

An application of this approach is found in Pindyck and Rotenberg. They estimate demands of capital, labor, energy and materials for the U.S. manufacturing sector, starting from a cost function. Because they do not solve the stochastic problem, they do not obtain the optimal factor-demand trajectories. But they obtain complete sets of short- and long-run elasticities. The effect of anticipated and unanticipated changes in the price of energy on factor input demands is then simulated. Note that simulations can only be carried out in a deterministic context, which "should provide a close approximation to actual behavior if the stochastic elements in the evolution of factor prices and the real interest rate are small" (Pindyck and Rotemberg, p. 1075).

In conclusion, specifying dynamic models in a deterministic framework relies on very strong assumptions. If a stochastic framework is maintained the dynamic model cannot in general be solved and needs to be approximated. In this case, only short-run and long-run solutions are obtained, and insights into the path of adjustment of the quasi-fixed factors are lost. Furthermore, simulations need to be made in a deterministic context.

Another class of models has been developed, using the assumption of static price expectations from the outset. As is explained below, these models can be solved for the long-run equilibrium values, and yield optimal (lon run) equations for the quasi-fixed inputs. Whether quasi-fixed inputs behave as such or as variable inputs can be tested since the variable input case is nested within the more general quasi-fixed input model (for example, see Vasavada and Ball).

IV.2.2. Deterministic dynamic models

After presenting the theoretical framework for this approach, some empirical applications are reviewed. In the final section, the assumption of adjustment costs, that underlies the dynamic equilibrium models, is discussed.

IV.2.2.1. Theoretical Framework

Beyond the use of static price expectations, the deterministic dynamic approach usually relies on the assumption of internal adjustment costs,[41] i.e. the lack of full adjustment of quasi-fixed inputs is due to factors internal to the firm. This assumption can be accommodated by specifying the production function of the firm as:

$$Y = F(X, Z, \dot{Z}, W, t), \qquad (IV.1)$$

where X is the vector of variable inputs, Z the quasi-fixed inputs, $\dot{Z}$ the investments (i.e. change in levels of quasi-fixed inputs) and W the exogenous inputs (i.e. those not controlled by the decision-maker, such as weather or policy variables) used to produce outputs Y at time t. If levels of the quasi-fixed inputs vary ($\dot{Z} \neq 0$), output falls for any given amount of X and Z, because of the need to devote resources to changing the stock rather than producing output. This diminuation in output brought about by $\dot{Z}$ not equal to 0 constitutes internal costs of adjustment.

The intertemporal profit maximization of the firm is the following:

$$\text{Max} \int_0^{\infty} [pF(X, Z, \dot{Z}, W, t) - lX - q\dot{Z}]\, e^{-rt} dt, \qquad (IV.2)$$

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[41] Adjustment costs can be specified as external. In that case, Y is not a function of $\dot{Z}$, and a separate cost-of adjustment function is estimated. An example of external cost-of-adjustment is given later.

where p is the output price vector, l the variable input price vector, q the prices of quasi-fixed factors, and r the discount rate.[42]

The deterministic cost-of-adjustment model can be estimated using either a primal or a dual approach. Both methods start from the above intertemporal profit maximization. The primal or direct method consists in actually solving for the optimal levels of the quasi-fixed factors. This has been done in two different ways. First, Craine assumes external adjustment costs and specifies a linearly homogeneous production function using one variable input (labor) and one quasi-fixed input (capital).[43] The method he develops requires the production function to be homogenous of degree one, and is limited to problems with only one variable input and one quasi-fixed input. It is therefore very restrictive. Thus, Craine does not directly specify the profit function. Second, Lopez (1985) assumes internal adjustment costs and writes the intertemporal profit maximization problem similar to equation *IV*.2. The first-order conditions concerning the quasi-fixed factors are derived using Euler's equations of the calculus of variation. With only one quasi-fixed factor (capital stock, K) the resulting system is reduced to one equation. The solution cannot in general be obtained, but it can be linearly approximated around K^*, the optimal value of capital stock, using the fact that $\dot{K}^*$ is then zero. This approximation yields the optimal (long run) equation for K (i.e. K^*). The coefficients of this equation represent the effect of exogenous variables, including output and variable input prices, on K^* . These values are necessary to compute long-run output supply or variable input demand elasticities.

Lopez's approach can accommodate problems with several variable inputs and does not require linearly homogenous production functions because it starts by specifying a profit function. However, as shown by Treadway, who developed the theoretical approach followed by Lopez,

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[42] For simplicity, no depreciation of quasi-fixed factors is assumed. Adding depreciation does not modify the approach, but complicates the presentation.

[43] Craine actually formulated a stochastic problem. However, because of the difficulty of solving stochastic dynamic problems, even with a limited number of variables, he assumed that the firm separated the randomness and the restricted adjustment into two problems, and solved them separately. Thus, he solved a deterministic cost-of-adjustment problem.

obtaining stable roots from the linear approximation of Z^* is guaranteed only if the production function (and hence its dual profit function) is quadratic.[44] The obtention of stable roots becomes very difficult, if not impossible, if the model includes more than one quasi-fixed factor. In such a case, the approach described below would be preferred.

The other approach to the deterministic dynamic problem is the dual model including the deterministic cost-of-adjustment mechanism. This approach is based on the theoretical work by McLaren and Cooper and by Epstein. They have established a full dynamic duality between the firm's production technology and its dual dynamic profit function. A generalized version of Hotelling's lemma is used to obtain expressions for variable input demands and optimal net investments (i.e. long-run demands) in quasi-fixed inputs.

In the short-run, firms are viewed as maximizing restricted variable profits, i.e. profits conditional on output prices, variable input prices, levels of the quasi-fixed inputs, and changes in those quasi-fixed input levels. In the long-run, firms are assumed to maximize the present value of the future stream of profits, called the value function.

The assumption of static price expectations enters in solving the long-run problem. Another way of stating this assumption is to say that relative prices observed in each base period are assumed to persist indefinitely. In the next period, these expectations will be altered as prices change and previous decisions will no longer be optimal. Consequently, in each time period, only that part of the decision corresponding to that time period is implemented. This implies that, under static expectations, the value function can be viewed as resulting from the static optimization of a dynamic objective function. Assuming a constant real rate of discount and the usual curvature properties of the technology, Epstein showed that the original dynamic optimization problem can be transformed into a static optimization problem by the use of the Hamilton-Jacobi equation.[45]

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[44] Lopez specified a normalized quadratic profit function.

[45] See Epstein for the theory. Applications include Taylor and Monson, and Vasavada and Chambers.

By this equation, the function maximized is defined as the maximum value of current profit plus the discounted present value of the marginal benefit of an optimal adjustment in net investment.

Thus, decision-making is assumed to follow two stages: first, the firm is assumed to pick quantities of variable inputs and outputs, and second the optimal level of the quasi-fixed inputs is determined by maximizing the discounted future stream of rents.

IV.2.2.2. Examples of the dual approach

The dual approach with costs of adjustments was applied to analysis of U.S. agriculture by Vasavada and Ball, Alexander, Vasavada and White, Taylor and Monson and by Vasavada and Chambers.[46] Vasavada and Ball analyzed the structure of input adjustments and found that durable equipment, farm produced durables, and family labor exhibited significant rigidities and thus behaved as quasi-fixed inputs in agricultural production. In contrast, the authors could not reject the hypothesis that real estate was a variable input. Alexander, Vasavada, and White estimated input demand and output supply equations for aggregate U.S. agriculture. Their model included three outputs (field crops, livestock and dairy, and fruits, nuts, and vegetables), two variable inputs (labor and intermediate inputs), and one quasi-fixed input (capital including durable equipment, farm-produced durables and land). They rejected the hypothesis that capital was a variable input, indicating that the slow adjustment of capital is a characteristic of U.S. agriculture. They also found that intermediate materials exhibited a complementary relationship with capital in both the short-run and the long-run while labor complemented capital in the short run and served as a substitute for capital in the long-run.

Taylor and Monson estimated a four equation input demand system for aggregate southeastern United States agriculture, using labor and materials as variable inputs and land and capital as

[46] Applications to other sectors include McLaren and Cooper, and Berndt, Morrison and Watkins.

quasi-fixed inputs. They concluded that both land and capital exhibited quasi-fixity, and that their rates of adjustment were independent. The various cross-price elasticities had the same sign in the short and long-run. Labor, for example, was a substitute for materials and capital and was a complement for land.

Vasavada and Chambers estimated a model similar to Taylor and Monson's, but specified all four inputs (labor, materials, land and capital) as quasi-fixed. Their results indicated that materials were a variable input (i.e., they did not exhibit quasi-fixity), and that the adjustment rates between the other inputs were not independent. However, some of their empirical results are questionable. For example, own-price elasticities are positive in the short run for labor and capital demands and remain positive in the long run for capital. Also, labor and capital were found to be inferior factors in the sense that less of these factors were used when output price increased.

Thus, modeling growth by specifying a deterministic model is attractive, because it provides the same information obtained by stochastic dynamic models (i.e. a differentiation between short- and long-run effects) while avoiding the empirical difficulties inherent in the stochastic models. This is made possible, however, by using the assumption of static price expectations which is, in general, highly simplistic in a dynamic environment.[47] The other assumption mentioned above -- that of adjustment costs -- is common to both stochastic and deterministic models.

IV.2.3. The cost-of-adjustment assumption

The cost-of-adjustment hypothesis as introduced by Lucas (1967a) states that investment disrupts production and hence imposes costs on the firm. Adjustment costs can be incorporated as internal to the firm or as external. When incorporated internally (as in the examples above) no

[47] When prices are for the most part policy determined, static price expectations become much more attractive.

additional assumption needs to be made. But, if adjustment costs are viewed as external to the firm, they need to be specified apart from the profit maximization problem. Such a specification is necessarily ad hoc, which explains its limited use in the literature.[48]

In most empirical works, adjustment costs are assumed to be internal. The implications of this assumption may not fit particular situations. Brown and Christensen write, "Departures from static equilibrium may result from factors other than internal costs of adjustment. For example, regulatory restrictions may hinder capital mobility. In such cases, dynamic equilibrium will be an inappropriate specification." Similarly, the literature reviewed on labor migration (see III.4.1.) showed that the movement of labor out of agriculture depends on factors both inside and outside the sector, many of them (such as the industrial wage) clearly non linked to adjustment costs in agriculture. For example, it was hypothesized that unemployment in the industrial sector reduces migration out of agriculture, by lowering the migrants' perceived probability of finding a job. Testing this hypothesis cannot be done in a framework of internal adjustment costs. Thus, the assumption of internal costs of adjustments may lend itself more naturally to capital investment than to labor transfers. In the present study, where both capital and labor transfers are important, this assumption is not appropriate.[49]

In conclusion, the ad hoc specification of external adjustment costs makes it a somewhat unattractive approach, and short-run disequilibrium can be due to factors outside the sector which is contrary to the assumption of internal adjustment costs. This dilemma reduces the attractiveness of currently available dynamic specifications. It raises the possibility of using an approach that builds on the quasi-fixed input concept to provide information on the short and long run, without depending on the adjustment cost assumption. Such an approach is described below.

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[48] External adjustment costs are usually assumed to be quadratic in investment. For example, see Craine.

[49] The entire cost-of-adjustment approach was criticized by Antle (1984), on the grounds that it could only capture input dynamics whereas agricultural production was in fact characterized by both input and output dynamics. It remains, however, the most common assumption used in dynamic analyses.

IV.3. Long-run variable profit function approach

The variable profit function approach does not require any assumption about the causes of short-run disequilibrium. It generates short- and long-run output supply and variable-input demand functions, as well as optimal levels of the quasi-fixed inputs, given other exogenous factors (prices, technology, and so on). Since the variable profit function makes no assumption about the causes of quasi-fixity of some resources, it provides no information about the adjustment paths or timing of adjustment between the short run (quasi-fixed factors fixed) and the long run (quasi-fixed factors adjusted to optimal values).

First, the theoretical model underlying this approach is presented. This is followed by a review of empirical work using this approach. Finally, the long-run equilibrium obtained with this static specification is compared to the long-run obtained under dynamic equilibrium assumptions.

IV.3.1. Theoretical framework

Similarly to dynamic programming, decision making is assumed in this approach to be two-staged. In the first stage (the short run), firms decide on the levels of outputs and variable inputs, given the levels of the quasi-fixed variables. In the second stage (the long run), the optimal levels of the quasi-fixed variables are determined. In both approaches, the short-run specifications are identical and consist in maximizing restricted variable profits. The differences are in the long-run assumptions and specifications, and on the treatment of adjustment costs.

The long-run variable profit function approach is based on duality theorems that have been little used in the literature. They show that the restricted variable profit function, specified for the short-run (quasi-fixed inputs fixed) also contains information about the long-run optimization problem (quasi-fixed inputs variable). As Berndt, Morrison and Watkins write: "What is not so obvious is that long-run elasticity estimates among both variable and (quasi)fixed inputs can also be retrieved from the short-run restricted variable cost function. Hence, estimation of a restricted short-run variable cost function can provide a complete characterization of short- and long-run elasticities". This approach maintains the assumption of short-run disequilibrium, but there is no need to make any assumption on the reasons for this disequilibrium (no need to assume whether adjustment costs are internal or external).

To develop this approach, write the variable profit function as:

$$\Pi = \Pi(P_o, r_v, Z, W),$$

where P_o is the vector of expected output prices, r_v the vector of variable input prices, Z the quasi-fixed inputs, and W the fixed or exogenous inputs. The short-run profit maximizing output supply and variable input demand functions are equal to or can be derived from the partial derivative of restricted variable profits with respect to the prices of, respectively, outputs and variable inputs:[50]

$$O_{SR} = \frac{\partial \Pi}{\partial P_o} = O_{SR}(P_o, r_v, Z, W)$$

$$V_{SR} = -\frac{\partial \Pi}{\partial r_v} = V_{SR}(P_o, r_v, Z, W)$$

To derive the long-run functions, it is necessary to use what Brown and Christensen refer to as the "full static equilibrium condition for a quasi-fixed factor". This condition simply states that the

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[50] In general, the first partial derivatives are the output supply and input demand equations but, in some cases, they are factor share equations from which supplies and demands can easily be derived. On another note, the extension of Shephard's lemma used here is often called Shephard-Uzawa-McFadden lemma. Many proofs of Shephard's lemma can be found in the literature. See for example Henderson and Quandt, p.118.

derivative of the restricted profit function with respect to the quantity of a fixed input Z_j in long-run equilibrium must equal the rental price of the fixed input r_j, which is:[51]

$$r_j = \frac{\partial \Pi}{\partial Z_j} = Z\,(P_o, r_v, Z, W)$$

Doing this for every quasi-fixed input yields a system of equations. By solving for the optimal Z's, the long-run profit-maximizing levels for the fixed inputs ($Z^{\bullet}$) can be computed:

$$Z^{\bullet} = Z^{\bullet}\,(P_o, r_v, r_z, W)$$

The long-run supply and variable input responses can then be obtained by substituting $Z^{\bullet}$ into the profit function, and by differentiating the resulting function $\Pi^{\bullet}$ with respect to the appropriate output and variable input prices.

The theoretical implications of using the restricted profit function have been explored by Lau. He established several relationships between long-run and short-run elasticities. One of these relationships is fundamental to our study. To present it, let P be the vector of prices of both outputs and variable inputs (i.e., $P = [P_{0,}r_V]$) , Z the vector of quasi-fixed input quantities, r the vector of their rental prices, and W the vector of exogenous and fixed factors. The short-run profit function can be written as: $\Pi = \Pi\,(P, Z, W)$, and the long-run profit function as: $\Pi^{\bullet} = \Pi^{\bullet}(P, r, W)$. In matrix form, Lau's relationship (p.150) is as follows:

$$\left[\frac{\partial^2 \Pi^{\bullet}}{\partial P^2}\right] = \left[\frac{\partial^2 \Pi}{\partial P^2}\right] + \left[\frac{\partial Z}{\partial P}\right]^t \left[\frac{\partial^2 \Pi}{\partial Z \partial P}\right]$$

To understand the economic meaning of this expression, it is easier to look at some elements of the matrices. Two such terms are considered next: one on the diagonal (own-price impact) and one off the diagonal (cross-price impact).

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[51] For a formal derivation, see Lau (p. 142) and Diewert (1974, p. 140).

For example, consider the long-run impact of an increase, say, in cereal price (P_C) on cereal production. The corresponding term is:

$$\frac{\partial^2 \Pi^*}{\partial P_C^2} = \frac{\partial^2 \Pi}{\partial P_C^2} + \sum_j \frac{\partial Z_j}{\partial P_C} \frac{\partial^2 \Pi}{\partial Z_j \partial P_C}$$

which is, by Shephard's lemma:

$$\frac{\partial Q_C^*}{\partial P_C} = \frac{\partial Q_C}{\partial P_C} + \sum_j \frac{\partial Z_j}{\partial P_C} \frac{\partial Q_C}{\partial Z_j}$$

where $\frac{\partial Q_C^*}{\partial P_C}$ represents the long-run impact of cereal price on cereal production (i.e., quasi-fixed factors at their equilibrium values before and after the change in P_C), $\frac{\partial Q_C}{\partial P_C}$ represents the short-run impact, $\frac{\partial Z_j}{\partial P_C}$ represents the impact of the increase in cereal price on the amount of quasi-fixed factor j, and $\frac{\partial Q_C}{\partial Z_j}$ is the marginal product of Z_j in cereal production. Thus, the long-run impact of cereal price on cereal production is decomposed into its short-run impact (movement along the short-run supply curve) and a sum of terms representing the impact on cereal output of the transfers of quasi-fixed factors induced by the increase in cereal price (i.e. a shift of the short-run supply curve).

The long-run impact of milk price on cereal output is given by:

$$\frac{\partial^2 \Pi^*}{\partial P_M \partial P_C} = \frac{\partial^2 \Pi}{\partial P_M \partial P_C} + \sum_j \frac{\partial Z_j}{\partial P_M} \frac{\partial^2 \Pi}{\partial Z_j \partial P_C}$$

which is:

$$\frac{\partial Q_C^*}{\partial P_M} = \frac{\partial Q_C}{\partial P_M} + \sum_j \frac{\partial Z_j}{\partial P_M} \frac{\partial Q_C}{\partial Z_j}$$

Again, the long-run impact of milk price on cereal output is equal to the short-run impact and to impacts resulting from the movements of quasi-fixed factors induced by the milk price increase.

Diewert (1982, p. 583ff.) presents a good historical review of the development of the concept of the variable profit function. He traces it back to Samuelson's national production function introduced in 1954. Duality theorems were developed in the 1960's and 1970's, including the relationship mentioned earlier between the rental prices of the quasi-fixed factors and their marginal profitability. However, empirical applications of this methodology remain scarce.

IV.3.2. Empirical applications

Studies making use of the variable profit function (or the variable cost function), and applying the Shephard-Uzawa-McFadden lemma to agriculture start with the work of Lau and Yotopoulos.[52] By using the aforementioned lemma, they derive variable input demand and output supply functions. But they do not allow for quasi-fixed inputs (i.e. they have only variable and fixed inputs) and thus cannot distinguish between short-run and long-run elasticities. Similarly, many recent studies use the variable profit (or cost) function and focus only on short-run results.[53] In a recent study, Grisley and Gitu explicitly set their problem (the analysis of turkey production in the Mid-Atlantic region) in a variable cost framework. However, the non-availability of data constrains them to restrict their study to its short-run dimensions, thus failing to exploit all the properties of the model. Caves, Christensen and Swanson compare the structure of production in the U.S. railroad industry using a total cost function, in which all inputs are considered variable, and a variable cost function, in which some inputs are viewed as fixed. They conclude that the variable cost function yields more credible estimates, i.e. estimates more in accord with theory. However, estimates reported are short-run values, no attempt being made to exploit the long-run information available in such a variable cost specification. Long run results are computed only from the total cost function.

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52 See Lau and Yotopoulos (1971,1972), and Yotopoulos and Lau (1973,1974).

53 Examples of cost function approaches include Binswanger (1974), Kako, and Ray. For examples using the profit function, see Sidhu and Baanante, Evenson (1982), Shumway, Antle (1985), and Huffman and Evenson (1982,1986). In all these studies, labor, capital (or both) remain fixed.

Applications making full use of the short-run and long-run properties of the variable profit (or cost) function are scarce in the literature. Mork estimates a variable cost function for the "goods and services sector" of the U. S., i.e. everything but agriculture and energy. The latter two are considered variable inputs in the production of goods and services, as is labor. Capital is quasi-fixed in his model. Using the generalized Leontieff functional form, Mork obtains short-run and long-run estimates of input demand elasticities. Mork presents his results without any explanation of his methodology.

Brown and Christensen apply a similar framework to an analysis of input substitution in U. S. agriculture. They consider one output (aggregate farm output), three variable inputs (hired labor services, capital services, material) one quasi-fixed input (family labor) and one fixed input (land). They start by specifying a variable cost function, which is used to determine the (short-run) demands for variable inputs, using Sheppard's lemma. Then, they define total cost as the sum of variable cost and expenditures for the quasi-fixed factors. The derivatives of total cost represent the variable input long-run demand functions. They can be expressed as a function of parameters of the short-run demand functions, and of the derivatives $\frac{\partial Z_i^*}{\partial P_j}$, where Z_i^* is the optimal level of quasi-fixed factor i , and P_j the price of variable factor j.

The authors specify a translog form for the variable cost function and compute short- and long-run price elasticities for the variable inputs, as well as short- and long-run elasticities of substitution among these inputs. Short-run values are obtained directly from Shephard's lemma. Obtaining long-run (or full static equilibrium) values requires the additional step of writing out the implicit total cost (CT) function and calculating the $\frac{\partial Z_i^*}{\partial P_j}$. Since most functional forms chosen for the cost function do not allow one to compute closed-form expressions for the Z_i^*, the authors compute the $\frac{\partial Z_i^*}{\partial P_j}$ indirectly. Their computation involves re-writing the total cost function as an implicit function, and using first-derivatives of this implicit function to calculate the $\frac{\partial Z_i^*}{\partial P_j}$. Computing elasticities also requires knowledge of the Z_i^* , optimal values of the quasi-fixed factors.

These are obtained by minimizing CT with respect to the Z_i^*, i.e. by numerically solving $\frac{\partial CT}{\partial Z_i^*}$. Details of the approach are given by Brown and Christensen (p. 212-213).

A comparison of the optimal Z_i^* with the actual values indicates the extent of disequilibrium in the sector. Brown and Christensen's estimates indicate that there was a very large surplus of family farm labor in the early postwar years in U. S. agriculture. In subsequent years both actual and optimal levels of family labor declined, but the ratio of optimal to actual, increased which indicates a movement toward equilibrium.

The authors then estimate the same model by assuming family labor to be a variable input (the often-made assumption of short-run full static equilibrium). The results obtained are not as satisfactory as those obtained by treating family labor as a quasi-fixed input, both in terms of plausibility of elasticities and in terms of curvature conditions (they were satisfied each year in the first case but were violated for eight years in the second case). Brown and Christensen conclude that the framework of variable cost (or profit) function is more appropriate for their study.

Although they consider only one quasi-fixed factor (family labor), the framework utilized by Brown and Christensen does not need to be limited to such a case. In fact, any inputs thought to be in disequilibrium can be treated as quasi-fixed, whether it is capital stocks (subject to the usual adjustment costs) or family labor (for which causes of disequilibrium may be more complex). In cases where more than one quasi-fixed input is used, however, numerically minimizing the total cost function with respect to all quasi-fixed factors simultaneously becomes a limiting factor. This can be resolved by using functional forms that allow obtention of closed-form expressions for the Z_i^* . As will be shown later, the only flexible functional form with that property is the quadratic.

As mentioned earlier, both the dynamic equilibrium and the variable profit function approaches yield long-run equilibrium input demand functions. The next section compares the long-run equilibrium, obtained respectively under dynamic and static assumptions.

IV.3.3. Long-run equilibrium under static and dynamic assumptions

Deriving output supply and variable input demand functions from a dynamic profit maximization framework theoretically yields both long-run demand functions and paths of adjustment (although we have seen that, practically, additional assumptions need to be made). Both the dynamic and the static approaches yield long-run functions, the long run being defined as the amount of time after which full adjustment of the quasi-fixed factors is realized. The question, then, is to determine whether or not both approaches yield equivalent long-run results.

Most studies using some kind of adjustment cost formulation take this equivalence as given. As Treadway puts it, it is "being apparently regarded as axiomatic that the inferences of static theory of the long-run should be reproduced by the dynamic theory". Thus Eisner and Strotz, in an analysis of business investment, build a model with one quasi-fixed input (plant size) set in a dynamic framework because they want to know the path of adjustment. They view the theory they developed as an extension of static theory, the latter describing only initial and final equilibrium positions, while their theory explains the passage from one to the next. Implied in this view is the conviction that static and dynamic theories yield the same long-run equilibrium. Lucas (1967b) extends the dynamic theory of investment to a multivariate framework, and also takes as a given the equivalence of static and dynamic approaches in representing long-run equilibrium.

This view also characterizes most of the studies reviewed earlier. Among the deterministic dynamic models, possible differences between static and dynamic long-run equilibrium is never mentioned as a reason to choose a dynamic approach. These studies are justified by the need to take into account quasi-fixity of inputs, but the authors do not acknowledge the possibility of doing so by the use of a variable profit (or cost) function. On the other hand, Pindyck and Rotemberg (stochastic dynamic framework) compare their work to Brown and Christensen (variable cost function). They acknowledge that Brown and Christensen's model provides a comparison of short-run versus long-run elasticities, but its limitation is not to describe the path to the long run, of great interest for their problem. Again, this indicates a conviction that both methods are equivalent in their long-run results.

An explicit comparison of long-run results obtained from static and dynamic specifications is given by Treadway. He compares long-run input functions obtained from a deterministic dynamic model and those obtained from a static model, the latter being obtained by making adjustment costs equal to zero.[54] In that case, maximizing profit directly yields the long-run functions. Treadway shows that, in general, static and dynamic formulations yield non comparable results because (a) long-run functions obtained from dynamic profit maximization are not theoretically constrained to be symmetric in prices (in contrast with static theory), and (b) dynamic results are not subject to any restriction similar to the negative definiteness of long-run demand functions obtained from static theory. Treadway shows that (b) is a consequence of (a). Thus, the real problem is the symmetry issue. Treadway explains that this problem does not occur in Lucas (1967b) or Eisner and Strotz, because they assume separability between stocks of quasi-fixed factors and marginal adjustment cost. In a simple case where labor and capital are the only quasi-fixed factors, this assumption means independence between the cost of adjustment in labor and capital, on one hand, and the equilibrium stocks of labor and capital, on the other hand. Interactions between the stocks, or between the costs of adjustment, are not restricted.

This assumption seems very reasonable in a study like ours. The reasons for labor stickiness in agriculture (i.e. adjustment cost of labor) are found mainly outside of the sector (unemployment) and in the various costs associated with relocation, but all of those are basically independent of the equilibrium amount of labor and capital in agriculture.

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[54] Note that Treadway's static model is different than the variable profit function approach, since the latter takes quasi-fixity into account.

In the same way, capital adjustment costs seem to be due more to factors such as the non-reversibility of capital, its discrete nature (cannot buy a half-harvester), which are all inherent to the nature of capital, but have little to do with the initial amounts of capital and labor in agriculture.

IV.4. Summary

In this chapter, two approaches to incorporate adjustment lags for some inputs were presented. In the first approach, the firm is assumed to be continuously in dynamic equilibrium. This approach uses dynamic programming and assumes that adjustment costs explain the short-run fixities exhibited by some inputs. These models provide adjustment paths for the quasi-fixed factors. However, empirical applications require the use of restrictive assumptions. In particular, this approach is usually applied to univariate analysis of production. Also, price expectations are usually assumed to be static, and adjustment costs are assumed to be either external or internal. The ad hoc specification of external adjustment costs makes it a somewhat unattractive approach, and short-run disequilibrium may be due to factors outside the sector, which is contrary to the assumption of internal adjustment costs.

The second approach is the long-run variable profit function approach. This is the approach we adopt in the study. An advantage of this approach is its compatibility with multivariate analysis. In addition, this approach does not require any assumption about the causes of short-run disequilibrium. It generates short- and long-run output supply and variable input demand functions as well as optimal levels of the quasi-fixed inputs, given other exogenous factors. However, it does not provide any information on the adjustment paths of the quasi-fixed factors between the short and the long run.

CHAPTER FIVE

EMPIRICAL MODEL

V.1. Introduction

This chapter is divided into five main sections. In the first section, the model used in this study is presented. Emphasis is placed on the choice of functional form. In the second section, the variables included in the empirical model are described. In the third section, this model is used to develop a series of tests concerning the hypotheses that were presented in chapter I. Estimation issues are discussed in the fourth section and the data used to estimate the model are described in the fifth section.

V.2. Presentation of the model

The model developed in this study is a sectoral model of the French agricultural sector.[55] It uses the long-run variable profit function approach, and includes the elements mentioned at the end of chapter III, i.e. technical change, structural change, price policies, and transfers of labor and capital between agriculture and the rest of the economy. Price policies are assumed exogenous, depending upon a European policy process that has little to do with the performance of the French agricultural

[55] The agricultural sector is assumed to have no significant influence on the non-agricultural sector because of their relative sizes: agriculture has been responsible for around 5 percent of the GNP over the period. However, Stoeckel (1985) disagrees with this assumption, noting that higher food prices resulting from the CAP impose costs on the rest of the economy.

sector.[56] Technical and structural change are also assumed exogenous in the model. On the other hand, all the variables that are controlled by the decision-maker are endogenized. This includes not only output supplies and use of variable inputs, but also determination of the optimal quantities of the quasi-fixed factors, family labor and capital.

This section is divided into three parts. First, the choice of functional form is explained. Then, the short-run model is presented in detail. Lastly, the derivation of the long-run results is described.

V.2.1. Choice of functional form

The question of which functional form to use is one that all empirical econometric studies must face. As discussed by Fuss, McFadden, and Mundlak, all functional forms implicitly impose maintained hypotheses on the analysis. This is critical since the outcome of a specific hypothesis test will depend not only on the validity of the hypothesis under examination but also on the validity of the maintained hypotheses used in the model. If invalid (or implausible) maintained hypotheses are imposed, later rejection in a specific hypothesis test may be a consequence of the invalidity of the maintained hypotheses rather than of the primary hypothesis which is tested. It is therefore useful to work with functional forms that embody few maintained hypotheses.

As shown by Fuss, McFadden, and Mundlak, the usual comparative statics properties of a production function at a point can be characterized by $(n + 1)(n + 2)/2$ distinct economic effects. The authors conclude (p. 231) that "a necessary and sufficient condition for a functional form to reproduce comparative statics effects at a point without imposing restrictions across these effects is

[56] In the past two years, the performance of the European agriculture as a whole has influenced the political process of price support determination through the EC budget constraint. However, there was little evidence of this happening earlier.

that it have (n + 1)(n + 2)/2 distinct parameters, such as would be provided by a Taylor series expansion to second-order."

However, in an econometric study like ours, the functional form needs to be fitted to observations over an extensive domain. In general, it will not be a second-order approximation to the true function at any chosen point. If the function is fitted for a point in the data, White points out that the approximation error from the Taylor series can be large for departures from that point.

To overcome this problem, two general approaches have been proposed in the literature. First, Barnett proposes to reduce the variation in the error term by using a generalization of Taylor series: the Laurent series. It consists of adding an analogous series with negative powers to the original Taylor series. Empirical tractability becomes a problem because of the data requirements, already stringent in our study as is explained later. A more serious problem is that there is no guarantee the the Laurent series can approximate globally the true function. All that can be said is that it behaves at least as well as the Taylor series expansion.

Second, Gallant proposes the use of the Fourier series method, that has the capability in principle to approximate globally the true function. But its use is very controversial. Weaver (1984) points out that Fourier series are necessarily truncated for empirical work, and nothing is known about the nature of the error introduced by truncation and, consequently, about the global behavior of the truncated series.

Chalfant compares results obtained with a Fourier series to those obtained with a Taylor series and found that the estimated elasticities were more unstable across the data with the Fourier specification, often having the wrong signs. The elasticities followed a cyclical pattern. King explains that this is not surprising, since the Fourier specification includes terms in sine and cosine. Pope points out that, although the Fourier flexible forms yield consistent estimates, they often have large standard errors: thus it is not surprising to find many coefficients with the wrong signs. As is often the case in econometric work, the choice is a trade-off between bias and instability. Given the large instability of the results obtained with the Fourier series, it seems worthwhile to reduce that variability at the cost of introducing some bias. This is what the Taylor series do (Chalfant).

Many functional forms can be interpreted as Taylor's expansions. A second-order Taylor's expansion of the function $y = f(x_1, x_2)$ is given in appendix A. It is explained that a Cobb-Douglas function can be viewed as a first-order expansion, while the normalized quadratic, translog, and Generalized Leontieff are all second-order expansions.

Being second-order expansions, the three latter functional forms will provide equally satisfactory representations of an arbitrary function at a point. According to Fuss, McFadden and Mundlak (p.237-240), "choice between them should be based on their quality as approximations to the true functions over the full domain of interest, if this can be assessed a priori, and on the ease with which hypotheses of interest can be stated as restrictions on parameters." There is no way to assess a priori which functional form would be a better approximation in this study, given the dearth of empirical profit functions estimated for French agriculture. However, as pointed out in IV.3.2. and will become more apparent later, there is a practical reason to choose the normalized quadratic functional form.

Given the large number of variables involved, it would be cumbersome to detail here the long-run variable profit function used for this study. This can be found in appendix B. A condensed specification of the normalized quadratic functional form is presented here:

$$\Pi = \beta_o + \sum_i \alpha_i P_i + \sum_j \mu_j Z_j + \sum_k \delta_k W_k + \frac{1}{2}\sum_i \sum_{i'} \lambda_{ii'} P_i P_{i'} + \frac{1}{2}\sum_j \sum_{j'} \gamma_{jj'} Z_j Z_{j'}$$

$$+ \frac{1}{2}\sum_k \sum_{k'} \chi_{kk'} W_k W_{k'} + \sum_i \sum_j \eta_{ij} P_i Z_j + \sum_i \sum_k \varphi_{ik} P_i W_k + \sum_j \sum_k \theta_{jk} Z_j W_k \qquad (V.1)$$

where P_i represents the expected output prices and the variable input prices, Z_j the quasi-fixed factors, and W_k the fixed and remaining exogenous variables. All the Greek letters are coefficients that need to be estimated; in the complete specification in appendix B all of these coefficients are given as b_{ij}'s. Since, in the complete specification, there is only one coefficient for each product of two variables (i.e. no separate coefficients for $P_iP_{i'}$ and $P_{i'}P_i$), the coefficients of the condensed form need to satisfy the restrictions: $\lambda_{ii'} = \lambda_{i'i}$, $\gamma_{jj'} = \gamma_{j'j}$, and $\chi_{kk'} = \chi_{k'k}$ for all relevant variables. In the following section, the normalized quadratic functional form defined above is used to derive the short- and long-run properties of the model. In specific computations, the detailed formulation of appendix B is used.

V.2.2. The short-run model

In the short run, quasi-fixed factors are held fixed. The short-run model consists of a set of four output supply and three input demand equations. The supply equations are: cereals (Q_C) , other crop products (Q_V) , milk (Q_M) , and other animal products (Q_N) . The input equations represent the demands by the agricultural sector for feeds (K_D) , fertilizer-energy (K_F) and hired labor (K_H) . All these equations are derived from the long-run variable profit function using the extension of Shephard's lemma that was mentioned in the previous chapter. As shown in appendix B, the use of a normalized quadratic functional form for the profit function yields linear supply and demand equations.

All short-run output supply and input demand equations are similar. Using the notation introduced above, they are:

$$\pm Q_i = \alpha_i + \lambda_{ii} P_i + \frac{1}{2} \sum_{i' \neq i} \lambda_{ii'} P_{i'} + \sum_j \eta_{ij} Z_j + \sum_k \varphi_{ik} W_k \qquad (V.2)$$

where the sign modifier of Q_i is positive if Q_i is an output and negative if it is an input, and the other variables and coefficients are as defined above.

The system of output supply and input demand equations satisfies the properties of homogeneity and symmetry. Linear homogeneity is characteristic of any theoretical supply or demand function and is discussed below in greater length. On the other hand, symmetry follows from the profit function approach. To understand how symmetry comes about in our model, let us look at two generic equation, Q_i and $Q_{i'}$ that can be any supply or demand equation. Using the above notation, the terms of interest in the profit function are:

$$\Pi = \beta_o + \alpha_i P_i + \alpha_{i'} P_{i'} + \ldots + \frac{1}{2}\lambda_{ii} P_i^2 + \frac{1}{2}\lambda_{i'i'} P_{i'}^2 + \ldots + \lambda_{ii'} P_i P_{i'}$$

Using Shephard's lemma:

$$\pm Q_i = \frac{\partial \Pi}{\partial P_i} = \alpha_i + \lambda_{ii} P_i + \lambda_{ii'} P_{i'}$$

$$\pm Q_{i'} = \frac{\partial \Pi}{\partial P_{i'}} = \alpha_{i'} + \lambda_{i'i'} P_{i'} + \lambda_{ii'} P_i$$

where the sign modifier of Q_i ($Q_{i'}$) is positive for a supply equation and negative for an input equation. In this example, the coefficient $\lambda_{ii'}$ is present in both equations. This is symmetry. Taking into account the different signs that Q_i and $Q_{i'}$ can take, the symmetry property can be expressed as:

$$\frac{\partial Q_i}{\partial P_{i'}} = \frac{\partial Q_{i'}}{\partial P_i}, \text{ if } Q_i \text{ and } Q_{i'} \text{ are both outputs or inputs}$$

$$\frac{\partial Q_i}{\partial P_{i'}} = -\frac{\partial Q_{i'}}{\partial P_i}, \text{ if } Q_i \text{ or } Q_{i'} \text{ is an output and the other an input.} \qquad (V.3)$$

A statistical test can be made to test whether this set of symmetry conditions is satisfied in our empirical analysis. A rejection of this test would imply a rejection of the adequacy of the profit function framework being utilized to analyze French agriculture.

In empirical analysis, it is easiest to estimate normalized profit functions, i.e. profit functions in which all prices are divided by one of the prices. To understand what happens with normalization, it is convenient to work with the first part of a typical equation. For example, from the expanded specification in appendix B, The cereals equation can be written as:

$$Q_C = b_C + b_{CC}P_C + b_{CV}P_V + b_{CM}P_M + b_{CN}P_N$$

$$+ b_{CF}\, r_F + b_{CH}\, r_H + b_{CD}\, r_D + \sum_{\psi} b_{CY} Y \qquad (V.4)$$

where P_C, P_V, P_M, and P_N are expected output prices respective of cereals, other crop products, milk, and other animal products; r_F, r_H, and r_D are input prices, respectively, of fertilizers and energy, hired labor, and feeds; and ψ is the set of non-price variables in the equation (the Z_j's and W_k's of equation V.2), Y representing a generic element of that set.

Normalizing with respect to the feeds price, r_D, yields the normalized cereals equation:

$$Q_C = b_C + b_{CC}\frac{P_C}{r_D} + b_{CV}\frac{P_V}{r_D} + b_{CM}\frac{P_M}{r_D} + b_{CN}\frac{P_N}{r_D}$$

$$+ b_{CF}\frac{r_F}{r_D} + b_{CH}\frac{r_H}{r_D} + b_{CD}\frac{r_D}{r_D} + \sum_{\psi} b_{CY} Y$$

which is:

$$Q_C = b_C^{\Delta} + b_{CC}\, P_C^{\Delta} + b_{CV}\, P_V^{\Delta} + b_{CM}\, P_M^{\Delta} + b_{CN}\, P_N^{\Delta}$$

$$+ b_{CF}\, r_F^{\Delta} + b_{CH}\, r_H^{\Delta} + \sum_{\psi} b_{CY} Y \qquad (V.5)$$

where $b_C^\Delta = b_C + b_{CD}$, and $P^\Delta = \frac{P_i}{r_D}$, for any output or input price $P_i \neq r_D$.

Normalizing thus reduces by one the number of variables to be estimated in each equation. Equation ($V.5$) is the equation estimated. It provides estimates of all the coefficients, except for b_C and b_{CD} . These can be recovered by making use of the linear homogeneity property of supply and demand functions. This property reflects the fact that, if all prices are multiplied (or divided) by the same constant, the quantity supplied (or demanded) does not change.

Recall that a function $Y = f(X_1, X_2, Z)$ is homogenous of degree k in the X_i's if the following relationship holds for any t:

$$f(tX_1, tX_2, Z) = t^k f(X_1, X_2, Z)$$

In the case of the original cereals equation ($V.4$), homogeneity of degree zero in prices means:

$$Q_C(t\rho, \psi) = t^0 Q_C(\rho, \psi) = Q_C(\rho, \psi) ,$$

where ρ is the set of output and variable input prices. More specifically, this is:

$$b_C + b_{CC} tP_C + b_{CV} tP_V + b_{CM} tP_M + b_{CN} tP_N + b_{CF} tr_F + b_{CH} tr_H + b_{CD} tr_D + \sum_\psi b_{CY} Y$$
$$= b_C + b_{CC} P_C + b_{CV} P_V + b_{CM} P_M + b_{CN} P_N + b_{CF} r_F + b_{CH} r_H + b_{CD} r_D + \sum_\psi b_{CY} Y$$

After re-arranging terms, the following equation is obtained:

$$(t - 1)(b_{CC} P_C + b_{CV} P_V + b_{CM} P_M + b_{CN} P_N + b_{CF} r_F + b_{CH} r_H + b_{CD} r_D) = 0 \qquad (V.6)$$

Since this needs to hold for any value of t, it implies that the linear combination of prices must be equal to zero. Imposing this relationship at the mean of the data provides the estimated value of b_{CD} . The constant term is then calculated as $b_C = b_C^\Delta - b_{CD}$. The true components of the estimated constant are computed similarly for each output or input equation.

Since normalizing the profit function with respect to r_D means that all terms in r_D become part of the intercept, it also implies that the corresponding input equation (K_D) , is not estimated. This is an empirical advantage (fewer coefficients needing to be determined by the data) if the missing coefficients can be recovered. Such is the case for the coefficients associated with price variables, but not for the coefficients associated with the non-price variables.

For any output or input price $P \neq r_D$, the relationship $b_{DP} = \pm\ b_{PD}$ holds by symmetry with a + sign if P is an input price and a $-$ sign if it is an output price. Since the b_{PD} can be computed as shown above, the b_{DP} can be derived by symmetry. Using the homogeneity of the feeds demand equation, b_{DD} can be recovered as well.

The remaining coefficients of the feeds equation are not subject to symmetry or homogeneity restriction, and thus cannot be computed from already estimated coefficients. Consequently, they need to be estimated separately. Hence, the approach followed is to compute the coefficients on r_D in all six equations from the coefficients of the estimated output supply and input demand equations (using homogeneity), obtain the cross-price coefficients in the last equation, K_D (using symmetry), and compute the own-price coefficient in K_D (using homogeneity). The last step is to estimate the missing coefficients in K_D. This is done as follows. The equation for K_D can be written as:

$$K_D = b_D + \sum_{\rho} b_{DP} P + \sum_{\psi} b_{DY} Y$$

where, again, P represents a generic element of ρ , the set of output and variable input price variables, and Y represents a generic element of ψ , the set of all non-price variables. The coefficients b_{DP} are known, and so we write:

$$K_D - \sum_{\rho} b_{DP} P = b_D + \sum_{\psi} b_{DY} Y \qquad (V.7)$$

The equation to estimate is thus: $K_D^{\Delta} = b_D + \sum_{\psi} b_{DY} Y$, where $K_D^{\Delta} = K_D - \sum_{\rho} b_{DP} P$.

V.2.3. The long-run model

As mentioned in the previous chaper, the determination of the long-run quantities requires obtaining optimal levels for the quasi-fixed inputs. For our study with family labor (L_A^F) and farm capital (K_A^F) quasi-fixed, determination of long-run equilibrium involves solving the system of equations:

$$r_K = \frac{\partial \Pi}{\partial K_A^F} \quad \text{and} \quad r_L = \frac{\partial \Pi}{\partial L_A^F} \tag{V.8}$$

where r_K and r_L are the opportunity costs of capital and labor, respectively. These equations presuppose knowledge of the coefficients of the profit function, at least of all the terms with K_A^F or L_A^F in them. Therefore, these coefficients need to be estimated.

In general, estimating the profit function is empirically impossible with time series data because of the large number of coefficients involved. However, the short-run model estimated above provides unbiased estimates for many of these coefficients. Using the coefficients associated with price variables estimated in the short-run model and the general form of (V.1) we can define:

$$\Pi^{\Delta} = \Pi - \sum_i \alpha_i P_i - \frac{1}{2}\sum_i\sum_{i'} \lambda_{ii'} P_i P_{i'} - \sum_i\sum_j \eta_{ij} P_i Z_j - \sum_i\sum_k \varphi_{ik} P_i W_k \tag{V.9}$$

where, again, P_i represents the expected output prices and the variable input prices, Z_j the quasi-fixed factors, and W_k the fixed and remaining exogenous variables. All the Greek letters are coefficients. The remaining coefficients of the profit function (see V.1) need to be estimated. Therefore, the equation to estimate is:

$$\begin{aligned}\Pi^{\Delta} = {} & \beta_o + \sum_j \mu_j Z_j + \sum_k \delta_k W_k + \frac{1}{2}\sum_j\sum_{j'} \gamma_{jj'} Z_j Z_{j'} \\ & + \frac{1}{2}\sum_k\sum_{k'} \chi_{kk'} W_k W_{k'} + \sum_j\sum_k \theta_{jk} Z_j W_k\end{aligned} \tag{V.10}$$

In this study, there are two quasi-fixed variables (the Z_j) and ten fixed or exogenous variables (the W_k). These variables are described in the following section. Taking into account the restrictions on the coefficients of the condensed form mentioned above, the number of coefficients to be estimated is 1 for β_0, 2 for μ_j, 10 for δ_k, 3 for $\gamma_{jj'}$, 55 for $\chi_{kk'}$, and 20 for θ_{jk}. In all, this amounts to 91 coefficients. Since the data set available goes from 1959 to 1984, i.e. 26 observations, estimation of all the coefficients is impossible. However, many of these coefficients are likely to be very close to zero, and thus can be fixed to zero without introducing any significant bias.[57]

Once the coefficients of the profit function are estimated, long-run equilibrium quantities of all outputs, variable inputs and optimal quasi-fixed factors can be computed without any further estimation. Details of the computations involved are provided in appendix B. The long-run optimal values of the quasi-factors, K_A^{F*} and L_A^{F*}, are obtained by solving the system of equations relating their rental prices to the corresponding derivatives of the profit function.[58] The equilibrium levels so obtained can be compared to the actual values of capital and labor: thus, disequilibrium in these two markets can be assessed, as well as the evolution of these disequilibria over time.

To obtain the long-run output supply and variable input demand equations, the quasi-fixed factors L_A^F and K_A^F are replaced in the already estimated short-run functions by their long-run equilibrium expressions, i.e. actual L_A^F and K_A^F are replaced by their long-run equilibrium values as a function of all the other variables in the model. This is presented in detail in appendix B (computations are carried through only for the long-run cereals supply, but can be extended easily for the other equations).

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57 The procedure we used to estimate the coefficients of the profit function is is explained in greater length in the following chapter.

58 As explained in the appendix, the system of equations is solvable because of the functional form chosen for the profit function. Other flexible functional forms would yield a system of equations that would not be analytically solvable.

Both short- and long-run models are used in the following chapter for hypothesis testing. These tests and the type of results that are likely to be generated by the model are discussed analytically in section V.4. First the variables used in the model are defined.

V.3. Definition of the variables

Presentation of the variables in the model is organized as follows. Output and input variables are successively discussed, the latter consisting of variable, quasi-fixed and fixed inputs. The discussion then focusses on the variables used to capture technological change, structural change and credit policy and ends with variables used to control for the effects of weather variations. A list of all the variables with their abbreviations is provided in table V.1.

As noted earlier (see table II.3), the two main products of French agriculture are cereals and milk , while other crop and animal products are also important.[59] As described above, emphasis is placed on these products, by disaggregating the agricultural sector into four sub-sectors: cereals (Q_C), other crop products (Q_V), milk (Q_M), and other animal products (Q_N). Again the respective prices of these commodities are noted, respectively, by P_C , P_V , P_M and P_N .

Output prices enter the profit function as expected prices, since actual prices are not generally known when planting decisions are made. In this study, output price expectations are represented by the corresponding one-year lagged market prices. This formulation of price expectations is based on the timing and nature of the price fixing mechanism in Europe. Target prices are set at a meeting of the agricultural ministers of all the EC countries, who negotiate starting from prices proposed

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[59] Cereals and milk are the two products for which there is the greatest production in the EC. Therefore, they are products which the Community exports, thereby lying at the root of the US-EC tensions mentioned in the first chapter.

Table V.1. Variables of the model

Q_C = Supply of cereals
Q_V = Supply of vegetable products other than cereals
Q_M = Supply of milk
Q_N = Supply of animal products other than milk
K_H = Demand for hired labor by the agricultural sector
K_F = Demand of fertilizer and energy inputs by the agricultural sector
K_D = Demand of feeds by the agricultural sector
K_A^F = Fixed capital (buildings and machinery) in the agricultural sector
L_A^F = Number of family members working in the agricultural sector
P_C = Expected market price of cereals
P_V = Expected market price of other vegetable products
P_M = Expected market price of milk
P_N = Expected market price of other animal products
r_D = Aggregate price of feeds
r_F = Aggregate price of fertilizer and energy inputs
r_H = Wage rate of hired labor in the agricultural sector
r_L = Opportunity cost of farm labor
r_K = Opportunity cost of fixed capital
RES = French public agricultural research expenditures
USP = Moving average of the level of total productivity in U.S. agriculture
REM = Cumulative amount of land consolidated at the end of the year
IVD = Retirement payments made to farmers during the year
SAF = Land sales handled by the SAFERs during the year
CR = Ratio of the average interest rate of farm loans to the market rate
CL = Area of cultivated land
PL = Area of pasture land
WEA = Average yearly deviations from normal rainfall
DUM = Dummy variable, taking the value 0 until 1975 and 1 afterwards

by the Commission.[60] Originally, support prices were meant to be fixed far enough in advance so that farmers had time to adjust their investment and production decisions. For example, the basic regulations for the cereals regime states that the intervention price for common wheat will be fixed before the first of August each year (i.e., a year's advance warning). Yet, as a matter of practice, this timetable was kept only during the first years. Since 1969, the target dates have been consistently missed (Harris et al.). Price proposals now tend to be submitted at the beginning of December, and are agreed upon the following spring (i.e., after sowing for that season has been completed). Nevertheless, the Commission proposals are known before planting in most cases. Thus, price expectations could be formulated as a function of Commission proposals. However, daily agricultural prices in Europe are "highly variable within a loose corset imposed by agricultural policy" (Coleman), while average yearly prices are found to be extremely close to intervention prices. Therefore, it is reasonable to assume that farmers will view the expected prices over the coming year as exogenous, and very close to the average market price they have received over the year (i.e. a one-year lagged price).[61]

On the input side, three inputs are assumed variable, two quasi-fixed, and one fixed. Variable inputs are feeds (K_D), fertilizer-energy (K_F) and hired labor (K_L) with prices respectively r_D , r_F , and r_H. They are quantitatively the most important inputs used in production, and are included separately to determine the impact of their prices on the growth and composition of output, as well as the influence of the various other sources of growth on the demands for these inputs by the agricultural sector. Everything else being constant, variable inputs usages are determined by the farmer based on observed contemporaneous prices that are assumed exogenous.

For both the wage rate of hired labor and the prices of variable inputs, the assumption of exogeneity is based on the relatively small size of the agricultural sector in the total economy. The

60 Except for fresh products such as fruits and vegetables, all products are subject to price intervention.

61 In practice, due to the negotiating process involved in price fixation, prices have never been lowered until the budget crisis of 1983. Using a lagged price as expected price is therefore reasonable over our period of study.

wage rate of hired labor in the agricultural sector is assumed to be mostly determined by the wage rate in industry, but the form of the dependency is not the focus of this study. The prices of variable inputs, produced by the industrial sector, are assumed to be determined in that sector, which amounts to assuming that they are supply determined prices. This is a common assumption in European agriculture studies since many authors consider that, in the EC, prices of "most non-agricultural inputs to the agricultural sector are not dependent on what happens in the agricultural sector" (Munk).

As was noted earlier (see table II.5), agricultural labor can be divided into owner-managers, family members, and wage earners. It is assumed here that, for any year, the amount of labor available in the family is fixed, and the farmer decides how much labor to hire based on his short-run profit maximization problem. The quantity of family labor is represented by L_A^F. As discussed earlier, the amount of family labor in agriculture is not necessarily at its optimum, due to various adjustment costs that need not be specified, and is therefore viewed in this study as quasi-fixed.[62]

The other quasi-fixed variable present in the model is fixed capital, K_A^F , which is essentially buildings and machinery. There, also, the fixity of capital assets in agriculture preclude full adjustment in the short-run. The opportunity costs of family labor and fixed capital are noted respectively r_L and r_K. The wage rate in the industrial sector is used as opportunity cost for family labor, and the prevailing interest rate as the opportunity cost for fixed capital.

62 If off-farm work is widely available, it can be argued that the amount of family labor in agriculture will be close to its optimium value. In that case, family labor should be treated as a variable input. Comparing the amounts of actual labor adjusted for part-time farming and of estimated optimal labor will indicate whether family labor should be specified as a quasi-fixed or as a variable input in French agriculture.

The last input in production is land. Because total land in production has not varied much in France during the post World War II period, land is considered as fixed. Land is represented by two variable: cultivated land (*CL*) and pasture land (*PL*).[63]

Technological change is captured by several variables. Agricultural research in France is hypothesized to be one of the major causes of technological change in French agriculture.[64] French public expenditures on agricultural research (*RES*) enter with a lag structure (several structures will be tested), from which marginal product for research can be computed. Since technical change is due not only to domestic research but also to internationally transferred technology, another variable is introduced in the model. This variable is a proxy for internationally available technology. The proxy chosen is a moving average of the level of total productivity in the U.S., represented by the variable *USP*. To take into account the lags involved in the transfers of technology, a five-year moving average of U.S. productivity is used.

Along with research, extension and the level of education of farmers need to be considered to capture technical change because of their impact on the adoption of new technologies.[65] Unfortunately, data availability precludes the use of these variables, which will bias upward the estimated marginal products of research.

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[63] Over the period of study, these areas have increased by 6 percent for pasture land and decreased by 7 percent for cultivated land. Nevertheless, these variables are considered as fixed factors in this study. By comparison, family labor has decreased by 55 percent and fixed capital increased by 83 percent over the period.

[64] It is important to note that the European Community does not have any organized research program. Research is left to individual member countries. On that point, Petit (1986) wrote "...emphasis should be placed on the various policies regarding the promotion of knowledge and technology. Strangely enough these policies, which are more and more recognized as critical for the agricultural development of less developed countries, have received very little attention in Community debates." See section V.6 for further discussion of the French research expenditure variable.

[65] The impact of education on agricultural output is broader that the technology adoption effect. In fact, schooling may have allocative as well as technical efficiency effects on production (Huffman). See section II.3.5.2. for a discussion of the array of French extension and agricultural eductional programs.

Structural change is represented by several policy variables that are French specific. These policies were successively discussed in II.4.1.2. Three variables are used in the study, capturing respectively the amount of land consolidated (*REM*), the amount of farm sales handled by the SAFERs (*SAF*), and the amount of retirement payments available to farmers (*IVD*). As was discussed in II.4.1.3., credit policies may have also played an important role in the development of French agricultural production. The variable *CR* is used to capture their potential effects. This variable measures the ratio of the preferential rates given to farmers to the prevailing market rates.

Finally, weather variations need to be controlled for. This is done in two ways. First, the variable *WEA* represents the average yearly deviations from normal rainfall. Second, a dummy variable was introduced in the model. Recall that, in chapter II, it was mentioned that the first oil shock of 1973 provoked a general economic crisis in France. Combined with the very severe drought of 1976, the crisis forced some enduring changes to come about in agriculture, causing farmers to modify their systems of production. This is taken into account by constructing a dummy variable, *DUM*, that takes the value one starting in 1976 and zero otherwise.

V.4. Tests developed from the model

A series of tests concerning the hypotheses of this study (see I.5) is developed in this section. Not all the hypotheses are discussed, the goal here being to show how the model described above is used for hypothesis testing. The major hypothesis of this study concerns the apportioning of sources of output growth between the different factors discussed above. How to address this hypothesis is explained first. Then, corollary tests developed from the short-run model are presented. Lastly, additional insights, provided by coefficients of the long-run model, are discussed.

V.4.1. Computation of sources of growth

Sources of output growth can be computed from the estimated supply equations as follows. In keeping with the notation used in the previous chapter, the estimated supply equation for Q_i can be written:

$$\hat{Q} = \hat{b}_i + \sum_{\rho} \hat{b}_{iP} P + \sum_{\psi} \hat{b}_{iY} Y$$

where ρ is the set of output and variable input prices, P represents a generic element of that set, ψ is the set of all non-price variables, and Y represents a generic element of that set. This equation is written for two periods t_1 and t_2 as:

$$\hat{Q}_i(t_1) = \hat{b}_i + \sum_{\rho} \hat{b}_{iP} P(t_1) + \sum_{\psi} \hat{b}_{iY} Y(t_1) \text{ , and}$$
$$\hat{Q}_i(t_2) = \hat{b}_i + \sum_{\rho} \hat{b}_{iP} P(t_2) + \sum_{\psi} \hat{b}_{iY} Y(t_2).$$

The growth in Q_i between the two time periods is:

$$\hat{Q}_i(t_2) - \hat{Q}_i(t_1) = \sum_{\rho} \hat{b}_{iP} [P(t_2) - P(t_1)] + \sum_{\psi} \hat{b}_{iY} [Y(t_2) - Y(t_1)]$$

For the sake of discussion, let us consider a specific variable, say P_C. Between the two time periods t_1 and t_2, the evolution of P_C is represented by the term $[P_C(t_2) - P_C(t_1)]$. As given by the expression above, the proportion of Q_i output growth due to the movement in P_C over this period is given by:

$$100\hat{b}_{iC} [P_C(t_2) - P_C(t_1)] [\hat{Q}_i(t_2) - \hat{Q}_i(t_1)]^{-1}$$

Thus, performing the above computations over the period of study provides a decomposition of any output growth into the proportions due to the movements in the explanatory variables present in that output equation. This is done in the next chapter.

V.4.2. Hypothesis testing in the short-run model

The first hypothesis stated in chapter I concerns the effect of domestic and internationally transferred research on agricultural growth. This is discussed first. The second and third hypotheses to be tested in the study deal with the effects of price support policies on output. These are addressed by considering the impact on cereal output of (1) an increase in the cereals price, and (2) an across the board increase in agricultural commodity prices.

As derived in appendix B, the short-run cereals output equation is written:

$$\begin{aligned} Q_c = {} & b_C + b_{CC}P_C + b_{CV}P_V + b_{CM}P_M + b_{CN}P_N + b_{CF}r_F + b_{CH}r_H + b_{CD}r_D \\ & + b_{CK}K_A^F + b_{CL}L_A^F + b_{CT}CL + b_{CA}PL + b_{CW}WEA + b_{CR}RES \\ & + b_{CU}USP + b_{CX}CR + b_{CB}REM + b_{CS}SAF + b_{CI}IVD + b_{CG}DUM \end{aligned} \qquad (V.11)$$

where all the variables are as defined in table V.1.

V.4.2.1. Short-run impact of technological change on cereals supply

The first variable used to capture technological change in the model is French public agricultural research expenditures. In agreement with the discussion in chapter III, research expenditures enter the model with a lag structure. The structure chosen is explained in the next chapter. As explained then, data limitations preclude the use of long lag lengths, which will bias the results obtained. However, even if individual coefficients on specific lags are biased, the sum of all the coefficients is likely to be little affected by truncating the lag.

In keeping with the notation above, the sum of the coefficients involving lagged values of French public research expenditures is noted by b_{CR} . This is an estimate of the marginal product of research in cereals production. Since b_{CR} is a sum of coefficients, it is straightforward to compute its variance and, consequently, to test whether or not the marginal product of research is significantly different from zero.

The impact of internationally available technology on cereals production is also tested. Recall that a five-year moving average of U.S. productivity is used as a proxy for that technology transfer. Testing this impact is done by testing the significance of the coefficient b_{CU}, from the short-run cereals output equation. This impact was hypothesized to be positive in the first hypothesis of this study, and this will be formally tested for the short-run model.

Once the impact of French research expenditures and of transferred technology are computed, the two impacts can be compared so as to test the main part of the first hypothesis of this study. To do so, a formal test will be developed to examine whether the impact of domestic research is greater than the impact of international transfers of technology.

V.4.2.2. Short-run impact of support prices on cereals supply

It was explained earlier that, because of the excess production in the EC, support prices (i.e., intervention prices) are very close to the observed market prices. The impact of the cereals price support on short-run cereals supply is therefore given by the coefficient b_{CC}, which will be tested for significance. If we accept the hypothesis of positive own-price supply elasticities, this coefficient is expected to be positive.

The impact of an across-the-board increase in support prices is given by the sum of coefficients:

$$b_{CC} + b_{CV} + b_{CM} + b_{CN}$$

The first coefficient represents movement along the short-term cereals supply curve, and the other coefficients reflect shifts of that curve due to potential transfers of resources between agricultural commodities. The term b_{CV} is expected to be negative, cereals competing with other crop products for land. However, the signs of the two other terms are harder to predict. Because cereals compete with milk and other animal products for some inputs, these coefficients could be negative; but cereals are used also for certain types of animal production which would tend to make the coefficients positive. The relative strength of these two effects will determine the signs of b_{CM} and b_{CN}, and this is an empirical question. However, it is likely that the cross-price effects will not outweigh the own-price effect, so that the impact of an across-the-board price increase on cereals output is expected to be positive.

V.4.3. Hypothesis testing in the long-run model

In this section, additional insights on the hypotheses of this study from results of estimation in long-run conditions are discussed. However, formal hypothesis testing is not possible, as is explained below. The same hypotheses as above are addressed using the long-run cereals supply equation, i.e. cereals supply with labor and capital adjusted to their optimal values $L_A^{F\blacksquare}$ and $K_A^{F\blacksquare}$. From appendix B (see B.9), the long-run cereals supply equation is written:

$$\begin{aligned} Q_C^{\blacksquare} = {} & b_C + b_K\Delta_{KC} + b_L\Delta_{LC} + r_K\Delta_{KC} + r_L\Delta_{LC} \\ & + \sum_{\rho}(b_{CP} + b_{CK}\Delta_{KP} + b_{CL}\Delta_{LP})P \\ & + \sum_{\zeta}(b_{CW} + b_{CK}\Delta_{KW} + b_{CL}\Delta_{LW})W \end{aligned} \qquad (V.12)$$

where, ρ, as defined above, is the set of all output and input prices (now including the non-farm wage rate, r_L and the interest rate, r_K), and ζ is the set of all the non-price variables, (with the exclusion of the quasi-fixed factors Z_j's) and P and W are generic elements of these two respective sets. The other expressions, defined in appendix B (see B.7 and B.8), are:

$$\Delta_{KP} = \frac{\partial K_A^{F^*}}{\partial P}, \quad \Delta_{LP} = \frac{\partial L_A^{F^*}}{\partial P}, \quad \Delta_{KW} = \frac{\partial K_A^{F^*}}{\partial W}, \quad \Delta_{LW} = \frac{\partial L_A^{F^*}}{\partial W} \qquad (V.13)$$

Since P_C is a specific element of ρ, Δ_{KC} and Δ_{LC}, are special cases of Δ_{KP} and Δ_{LP}, respectively.

V.4.3.1. Long-run impact of French research on cereals supply

From equation V.12, the long-run marginal product of research in cereals production is given by:

$$b_{CR} + b_{CK}\Delta_{KR} + b_{CL}\Delta_{LR} \ .$$

The first-term, b_{CR}, has already been discussed. It is the short-run marginal product of research in cereals production, expected to be positive. The second term can be written as follows:

$$b_{CK}\Delta_{KR} = \frac{\partial Q_C}{\partial K_A^F} \ \frac{\partial K_A^{F^*}}{\partial R} \ .$$

This term represents the additional impact of research on cereals output through capital formation. It consists of the product of the marginal product of capital in cereals production, expected to be positive, and of the impact of research on fixed capital optimal values. To sign this latter term, it is useful to consider how it was computed. From appendix B (see B.8), this term is:

$$\frac{\partial K_A^{F^*}}{\partial R} = -a_{KK}b_{KR} - a_{KL}b_{LR} \, .$$

The two numbers a_{KK} and a_{KL} are obtained by inversing a matrix of estimated coefficients of the profit function. These coefficients are difficult to sign. However, this can be done by noticing that (see B.5):

$$a_{KK} = \frac{\partial K_A^{F^*}}{\partial r_K} \quad \text{and} \quad a_{KL} = \frac{\partial K_A^{F^*}}{\partial r_L}$$

In keeping with the assumption of negatively sloped input demand, we expect $\frac{\partial K_A^{F*}}{\partial r_K}$ to be negative. It is also expected that labor and capital are substitutes in cereals production, and so $\frac{\partial K_A^{F*}}{\partial r_L}$ is expected to be positive.

The two other coefficients, b_{KR} and b_{LR}, are estimated coefficients in the profit function, respectively:

$$b_{KR} = \frac{\partial^2 \Pi}{\partial K_A^F \, \partial R} \quad \text{and} \quad b_{LR} = \frac{\partial^2 \Pi}{\partial L_A^F \, \partial R}$$

The sign of these coefficients is very hard to predict, and so the term $\frac{\partial K_A^{F*}}{\partial R}$ cannot be signed a-priori. However, if technical change has been labor-saving and capital augmenting in French agriculture over the period of study, this term will be positive.

Therefore, the second term in the long-run marginal product of research in cereals production represents the additional (i.e. after short-run impact) effect of research on cereals output due to optimal adjustment in the capital market.

Similarly, the third term in the long-run marginal product of research represents the additional impact of research on cereals output due to optimal adjustment in the labor market. This term can be written:

$$b_{CL}\Delta_{LR} = \frac{\partial Q_C}{\partial L_A^F} \frac{\partial L_A^{F*}}{\partial R} \quad .$$

This is the product of the marginal product of labor in cereals production expected to be positive, and of the impact of research on the optimal quantity of family labor. This latter term can be written:

$$\frac{\partial L_A^{F^*}}{\partial R} = -a_{LK}b_{KR} - a_{LL}b_{LR} = b_{KR}\frac{\partial L_A^{F^*}}{\partial r_K} + b_{LR}\frac{\partial L_A^{F^*}}{\partial r_L}$$

Since labor and capital are expected to act as substitute inputs in cereals production, $\frac{\partial L_A^{F^*}}{\partial r_K}$ is expected to be positive. Also, $\frac{\partial L_A^{F^*}}{\partial r_L}$ is expected to be negative, representing the own-price effect in the labor demand function. However, the terms b_{KR} and b_{LR} cannot be signed a-priori, and so neither can the term $\frac{\partial L_A^{F^*}}{\partial R}$. However, one might hypothesize that research expenditures would lower the optimal amount of family labor in agriculture.[66]

All long-run coefficients have a structure similar to that of the research term that was just discussed. Thus, long-run coefficients are the sum of the corresponding short-run coefficients and of terms representing the additional impacts due to optimal adjustments of the quasi-fixed factors, labor and capital. These additional terms are computed from coefficients estimated from both the short-run output supply and input demand system, and the remaining coefficients of the profit function (see section V.2.3). The process followed to compute these additional terms involves inverting a matrix of estimated coefficients (see appendix B, from B.4 to B.5), so that these terms are nonlinear combinations of estimated coefficients. Furthermore, the covariances between coefficients estimated from the short-run model and coefficients provided by estimation of the remaining terms of the profit function are not known. Therefore, the variances of the coefficients of the long-run output supply and input demand functions cannot be computed, and significance levels cannot be attached to these coefficients. Consequently, formal hypothesis testing is not possible with the long-run results.

In conclusion, the long-run marginal product of research in cereals production has been shown to consist of three parts. The first represents the short-run (quasi-fixed factors fixed) impact,

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[66] This would be the case for biased technological change. It could also be argued that, by making agriculture more profitable, research expenditures have slowed down migration out of the sector, thus having a positive impact on the amount of family labor in the sector.

expected to be positive. The second and third represent additional impacts due to full adjustment, respectively in the capital and labor markets. If research is assumed to be labor saving, its impact on cereals production will be positive through the capital market and negative through the labor market, these two effects taking into account labor-capital substitution. If the impact is expected to be greater through the capital than through the labor market, the long-run marginal product of research will be greater than its short-run counterpart.

V.4.3.2. Long-run impact of internationally available technology

The long-run impact on cereals production of internationally available technology is given by:

$$b_{CU} + b_{CK}\Delta_{KU} + b_{CL}\Delta_{LU}.$$

This consists of a short-run impact, and of additional impacts due to adjustments in the capital and labor markets. As discussed earlier, the short-run impact (b_{CU}) is expected to be positive.

The two other terms can be decomposed in a manner analogous to that just done for French research expenditures. It is natural to expect that the bias of technological change does not depend on the source of the change, i.e. whether it is due to French research expenditures or to technology transfers from the outside. Thus, it is expected that internationally transferred research (USP) will produce results similar to those obtained with French research.

V.4.3.3. Long-run impact of cereals price on cereals supply

The long-run impact of cereals price on cereals supply is given by:

$$b_{CC} + b_{CK}\Delta_{KC} + b_{CL}\Delta_{LC} \quad .$$

As before, the long-run impact can be decomposed in a short-run impact (b_{CC}), and in additional impacts due to optimal adjustments in the capital and labor markets, respectively represented by $b_{CK}\,\Delta_{KC}$ and $b_{CL}\,\Delta_{LC}$.

The short-run impact of cereals price on cereals supply above was assumed earlier to be positive. The long-run effects can be decomposed as was done earlier. The term involving capital, can be written, using V.13:

$$b_{CK}\,\Delta_{KC} = \frac{\partial Q_C}{\partial K_A^F}\frac{\partial K_A^{F^*}}{\partial P_C} \quad .$$

This is the product of the marginal product of capital in cereals production, expected to be positive, and of the impact of cereals price on the optimal value of fixed capital. It is expected that, when this factor of production becomes variable (the long run), an increase in P_C is likely to draw resources into the sector, and so $\frac{\partial K_A^{F^*}}{\partial P_C}$ is expected to be positive. Therefore, the term involving optimal adjustments in the capital market is expected to be positive.

An analogous discussion can be made for the last term in the long-run impact of cereals price, i.e., the term involving optimal adjustments in the labor market. This term is:

$$b_{CL}\,\Delta_{LC} = \frac{\partial Q_C}{\partial L_A^F}\frac{\partial L_A^{F^*}}{\partial P_C} \quad .$$

This is the product of the marginal product of family labor in cereals production, expected to be positive, and of the impact of cereals price on the optimal value of family labor, which is also expected to be positive.

In conclusion, the long-run impact of cereals price on cereals output is decomposed into (1) a short-run effect, (2) an additional effect due to optimal adjustments in the capital market, and (3) an analogous effect due to optimal adjustments in the labor market. All these effects are expected to be positive. Thus, the long-run effect of an increase in cereals price should be larger than the short-run effect. The magnitude of the difference is to be estimated empirically.

V.4.3.4. Long-run impact of agricultural prices on cereals supply

If all output prices increase, the resulting effect on Q_c^* is given by:

$$(\sum_{o} b_{CO}) + b_{CK}(\sum_{o} \Delta_{KO}) + b_{CL}(\sum_{o} \Delta_{LO})$$

where O is a generic element of o, the set of the four output prices P_C, P_V, P_M, P_N , and the terms have been grouped to show the short-run effect and the long-run effects due to optimal adjustment, first of capital and then of labor.

The short-run effect consists of the sum $b_{CC} + b_{CV} + b_{CM} + b_{CN}$. As discussed earlier, this term is expected to be positive, and could be greater or smaller than b_{CC}.

The first long-run term consists of the product of b_{CK}, already assured to be positive, and of the term:

$$\sum_{o} \Delta_{OK} = \frac{\partial K_A^{F^*}}{\partial P_C} + \frac{\partial K_A^{F^*}}{\partial P_V} + \frac{\partial K_A^{F^*}}{\partial P_M} + \frac{\partial K_A^{F^*}}{\partial P_N} \ .$$

It is shown above that $\frac{\partial K_A^{F^*}}{\partial P_C}$ is expected to be positive. The discussion that led to that conclusion could be repeated for any output price, and so all the above terms are expected to be positive. In the same way, the last long-run term consists of the product of b_{CL} and of a sum of terms representing the impacts of output prices on the optimal levels of labor in agriculture, all of which are assumed to be positive.

In conclusion, the long-run impact of an across-the-board increase in agricultural prices consists of the three effects: short-run impact, impact due to adjustment in the capital market, and impact due to adjustment in the labor market. All these effects are expected to be positive. Thus, the long-run impact is expected to be greater than the short-run impact. It is difficult to determine whether or not this long-run impact is greater than what is obtained as a response only to cereals price, because of negative terms due to inter-commodity substitution and to labor-capital substitution. This will be examined empirically.

This concludes the section on hypothesis testing. Before looking at the results of the model, the estimation procedures and the data series used in estimation will be discussed.

V.5. Estimation issues

As explained in section V.2., estimation of the short-run model is two-staged. The normalized model consisting of the four output and two input functions is estimated first, and the equation for input demand for feeds is then estimated.

It is to be expected that any shock affecting one output or input equation will also affect several other equations, thus making their error terms correlated. To correct for this correlation, the first six equations need to be estimated jointly.

In the case where the right-hand side variables are the same in all the equations, joint estimation by generalized least squares gives the exact same results as ordinary least squares.[67] This result does not apply for this study, since some asymmetric assumptions are made that reduce the number of

[67] For a proof, see Kmenta, p. 258.

parameters to be estimated (these are discussed in the next chapter). Consequently, joint estimation of the system of equations is used here.

Joint estimation is also necessary to be able to test and/or impose the symmetry restrictions discussed earlier. Testing these restrictions is important, since their rejection would imply a rejection of the profit function model. Further, these restrictions need to be imposed in order to obtain the long-run characteristics of the model, since one needs to substitute estimated parameters into the profit function and the symmetry conditions ensure a unique estimate of these parameters.

The estimation procedure adopted in this study is Zellner's estimation for seemingly unrelated regression. It consists of using ordinary least squares (OLS) initially, then estimating the variance-covariance matrix of the error terms of all the equations, from the OLS residuals. The estimated variance-covariance matrix is then used to perform generalized least squares estimation on the system of equations. This method is explained in detail by Judge et al. (p. 466-469).

As described above, the coefficients of the price variables in the last equation (demand for feeds) are computed from the estimated system, using the properties of symmetry and homogeneity. These coefficients are then fixed in the feeds equation, and the remaining coefficients are obtained by performing OLS. The equation estimated uses the non-price variables as explanatory variables, and the quantity variable adjusted by the already estimated coefficients times the corresponding variables as the dependent variable (see equation V.10).

V.6. Data used in estimation

The data used in this study covers the period 1959-1984. Many statistical series were not reported prior to that period, constraining the analysis to start in 1959.[68] In this section, the nature and origin of the data series used in this study are discussed. A complete listing of the data is given in appendix C.[69] As detailed below, most of the data comes from published sources. Exceptions concern the series used (1) for both hired and family labor in agriculture, (2) for the interest rates given to farmers, and (3) for French public expenditures on agricultural research. The first two series come from existing but unpublished data; the last one was developed for the needs of this study.

The model is estimated in real terms. All variables representing prices or values (e.g. capital, research expenditures) were deflated using the price deflator of the French Gross National Product. This series was taken from variable issues of Annuaire Statistique de la France, published by INSEE. Notice that estimation of the short-run output supply and input demand equations is made with normalized prices, so that the use of real or nominal prices in that estimation would produce the same results.

V.6.1. Output prices and quantities

Since agricultural production is divided into four aggregate outputs: cereals (C), other crop products (V), milk (M), and other animal products (N), price and quantity series are needed for each of these categories.

The price series have been provided by A. Hayem, then at the Ministry of Agriculture, and are part of the data set used for MAGALI, a short- and medium-run model of French agriculture, in

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68 Longer series are available for most prices and quantities. However, data collection was formally structured in the late fifties in France, and several researchers advised us against using any data prior to 1959 because of its poor reliability. Also, observations from 1976 were dropped from the data set because of unusually bad weather that year which could not be captured adequately by the weather variable available for the study (see section V.3).

69 Recall that a list of the variables can be found in table V.1.

which agricultural production is very disaggregated. That model is used by both the Ministry of Agriculture and the Ministry of Finance for short-run prediction. It does not include technical or structural change, nor does it attempt to determine long-run elasticities. Output prices used in MAGALI originally come from various issues of "Comptes de l'Agriculture", published by INSEE (Institut National de la Statistique et des Etudes Economiques). Prices are nominal and are given as indices, with base one in 1970.

The quantity series are obtained as follows. First, series on value of production are obtained from the same INSEE publication as above (they are noted V_i below). These series give the nominal value of each product, expressed in millions of francs. The quantity series are then obtained by dividing each production value by its corresponding price index. Therefore, what is obtained is a quantity index. What is important is that the product $P_i \times Q_i = V_i$ is in millions of francs for all outputs, ensuring consistent units in the profit function.

The breakdown of commodities used in the study does not exactly match the series provided by INSEE. Some aggregations had to be made. On the crops side, data series were available for cereals and for total crops, the latter being the aggregate of our two variables: cereals and other crop products. Since data is not given for all individual commodities within the total crops category, it is necessary to obtain the series for "other crop products" by disaggregation. The value of production for the latter variable was obtained by subtracting the value of cereals from the total value for crops. The price of total crops published by INSEE is a weighted average of individual commodity prices. Out of a total weight of 4513, cereals are weighted 1682. The weight for "other crop products" can be obtained by the difference (2831), and the values of P_V are obtained using the aggregation formula:

$$P_C w_C + P_V w_V = P_T (w_C + w_V)$$

where w_C (w_V) is the weight attributed to cereals (other crop products) in the total crop price index represented by P_T.

Once P_V is computed, Q_V is obtained by dividing the corresponding value of production by P_V.

On the animal side, data in value and prices was reported for all the main aggregates: milk, beef, veal, pork, horses, sheep and goat, poultry, eggs, and other product. For each of these categories, a quantity index is obtained by dividing value by price. We thus obtain Q_M . The variable Q_N is obtained by adding the quantities of all commodities but milk, and P_N is then obtained by dividing the sum of the same production values by Q_N. Again, this procedure ensures consistent units with values in millions of francs.

V.6.2. Variable input prices and quantities

Variable inputs are grouped into three categories: feeds, fertilizer and energy, and hired labor.

The quantity and price data for the first two input categories were obtained from the same source as the output data series, i.e. INSEE data collected for the MAGALI model. Prices are again nominal price indices with base one in 1970. Nominal values of input used are given in millions of francs, so these units match the output units. Quantity indexes are again obtained by dividing values by their corresponding prices.

The variables dealing with hired labor have been obtained differently, using the same INSEE publications mentioned in the output section. INSEE reports agricultural labor statistics only every five or seven years, which are the years when a census is taken. Fortunately, I was able to obtain an annual series on agricultural labor, divided into family labor and hired labor, from L. Vernière., of the Ministry of Planning. These series are those used in the MAGALI model, on which L. Vernière also works, and have been adjusted for part-time farming. The series on hired labor presented in appendix C is in thousands of workers. The INSEE publications were used to obtain wage values for hired labor. Two series were added, the first being the total yearly amount paid to hired farm workers, and the second being the social charges paid by farm-owners on behalf of farm workers. The two series need to be added in order to obtain the cost of hired labor. Both series were originally in millions of francs. Dividing the total cost of hired labor by the number of workers yields a wage per worker expressed in thousands of francs. To obtain unit consistency, the product of wage by number of workers must be in millions of francs. Wages is in thousands of francs per worker or, equivalently, in millions of francs per thousand workers; since the number of workers is also in thousands, the product of these two variables is in millions of francs, and is consistent with the rest of the outputs and inputs.

V.6.3. Quasi-fixed factors

The two quasi-fixed factors found in this study are family labor and capital. As mentioned above, the data series on family labor are those used for the MAGALI model and have been provided by L. Vernière. The series is in thousand workers and has been corrected for part-time labor.[70] The opportunity cost of farm labor, r_L, is taken to be the minimum guaranteed wage in industry, i.e. the industrial wage for unskilled labor. This series was obtained from various issues of Annuaire Statistique de la France, a publication of INSEE. Data is given in number of francs per worker, and have been divided by a thousand to bring them to thousands of francs per worker, and thus be consistent with the rest of the output and input prices. The series was deflated using the price deflator of the French Gross National Product.

The fixed capital series was taken from the 1984 volume of "Comptes de L'Agriculture", published by INSEE. It gives the total value of farm buildings and machinery in millions of 1970 francs. The opportunity cost of capital is taken to be the long-term interest rate, i.e. the return that

[70] The nature of the correction was not communicated.

capital could receive if used in other sectors of the economy. This series, the variable r_K, was taken from various issues of Annuaire Statistique de la France, published by INSEE.

V.6.4. Technological change

Recall that technological change is captured by two variables in this study: French research expenditures, and a proxy for internationally available technology.

After checking with several librarians and researchers in France, it became apparent that no published series was available on French public agricultural research expenditures. Such a series was compiled for this study, using unpublished expense records from the Ministry of Agriculture. With the help of Mrs. Quiquère, who works at the Ministry of Agriculture, I went back to the actual expenses incurred for the years 1959 through 1981. Data for the years 1982 through 1984 was given as budgeted expenses, since the records of actual expenses had not yet been put together. Except for these later years, the data series represented expenditures in thousands of francs incurred by the major public research institutions in France: INRA (Institut National de la Recherche Agronomique), by far the most important, and three inter-related institutions focused on agricultural machinery and water management. INRA expenditures consistently represent over 95% of public research expenditures.

The variable used as a proxy for internationally available technology is the average yearly productivity in U.S. agriculture. It was chosen because of the leading role of the U.S. in agricultural technology. Productivity is measured as an index. The data was taken from various issues of Agricultural Statistics, a publication of USDA.

V.6.5. Agricultural policies

Four variables are included to capture French-specific agricultural policies that were discussed in chapter II.

First, consolidation is represented by the variable *REM*, which is the cumulative area consolidated in France at the end of each year. This variable needs to be lagged in the model. The data was taken from various issues of Annuaire de Statistique Agricole, published by SCEES, which is an agency of the Ministry of Agriculture. Area consolidated is given in hectares (1 hectare = 2.47 acres).

Second, recall that agencies (the SAFERs) have been set up to redistribute some of the land that comes to the market with the avowed goal of farm enlargement. This is captured by the variable *SAF*, which gives the yearly acreage sold by these agencies, in hectares. Data was taken from various issues of Annuaire de Statistique Agricole. This variable is also lagged one year in the estimated model.

Third, elderly farmers have been encouraged to accept early retirement by being offered retirement payments. The total amount of retirement payments made yearly to farmers, in thousands of francs, is given by the variable *IVD*. Again, this data series comes from various issues of Annuaire de Statistique Agricole and is deflated before inclusion in the estimated model.

Lastly, credit policy was identified in chapter II as an important policy instrument, through the granting by the Crédit Agricole of loans below market rates to farmers fulfilling certain conditions. This information is not published and the Crédit Agricole does not appear willing to release it.[71]

[71] Jean-Marc Boussard, a researcher at INRA, suggested that this data is difficult to obtain for political reasons. Every year, the Ministry of Finance reimburses the Crédit Agricole for any costs incurred by the latter because of the below market rate loans. This operation was described to me as a bargaining process, explaining why the Crédit Agricole does not release any potentially sensitive information.

Fortunately, this information was included in the MAGALI model, and A. Hayem provided me with detailed information on the rates and amounts of the various types of loans given to farmers by the Crédit Agricole, both at market and preferred rates. An aggregate rate was computed, by weighing the rate given for each type of loan by the corresponding amount loaned. This is given by the variable *CR*. In the model, this variable is divided by the variable r_K, which is the market rate for long-term loans. The latter variable comes from various issues of Annuaire Statistique de la France, published by INSEE.

V.6.6. Other variables

Land, in this study, is represented by two variables: *CL* is the amount of cultivated land, and *PL* is the amount of pasture land. Both variables are expressed in thousands of acres, and are taken from various issues of Annuaire de Statistique Agricole, published by SCEES.

Weather is captured by the variable *WEA*, average yearly deviations from normal rainfall. Six stations were chosen, each in one of the main production regions.[72] For each of these stations, the yearly amount of rain (in millimeters) as well as the average rainfall since 1931 was provided by various issues of Annuaire de Statistique Agricole. Deviations from the average were computed for each of the stations. These deviations were then averaged to obtain the variable *WEA*.

Lastly, recall that a dummy variable is used with value one starting in 1976 to capture the changes provoked by the first oil shock of 1973 and the extreme drought of 1976.

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[72] These stations are Auxerre, Clermont-Ferrand, Lille, Marignane, Pau, and Paris.

V.7. Summary of model specification

To summarize, in this study we estimate a variable profit function model using annual data from 1959 to 1984. Observations for 1976 were dropped from the data set because of unusually bad weather that year which could not be captured adequately by the weather variable available for the study (see section V.3).

In our model, profits are a function of variable input prices and expected output prices, everything else being constant. It is assumed in this study that farmers view the expected prices over the coming year as exogenous and very close to the average market prices they received in the recent past.[73] Therefore, output prices are lagged one period in the model.

Variable input usages are determined by the farmer based on observed prices, and thus current values of input prices are used in the model.

Two inputs (family labor and capital) are treated as quasi-fixed, while land (divided into cultivated land and pasture land) is viewed as fixed. Current values of these inputs are used, since the impact of inputs on outputs is contemporaneous. Since the value of capital was reported in nominal terms, it was deflated using the price deflator of the French Gross National Product.

Technological change variables impact production over several years, and so a lag structure needs to be used. This is discussed further when the impacts of these variables are reported. French research expenditures were in nominal terms, and were consequently deflated using the same deflator as above. International availability of technology is measured by an index of average productivity in U.S. agriculture.

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[73] For a discussion of this assumption, see V.3.

On the policy side, the variable measuring retirement payments was in nominal terms, and was also deflated. The variable used to capture credit policy is the ratio of two loan rates and did not require deflation. The variable representing the cumulative area consolidated at the end of a year is lagged one year in the estimated model. The variable representing distribution of land by government agencies over the year is also lagged one year, since land distributed during the year is not likely to be brought into production before the following year.

Finally, two variables are weather-related in the model, as was explained earlier. The first one measures yearly deviations from normal rainfall. Current values of this variable are used. The other one is the dummy variable introduced to take into account the combined effect of the oil shock of 1973 and of the drought of 1976 (see chapter II). This variable takes the value one starting in 1976, and zero otherwise.

Results of estimation of the model described above are presented in the next chapter.

CHAPTER SIX

RESULTS AND IMPLICATIONS

VI.1. Introduction

In the following discussion, the system of the four output supply and three input demand equations derived from the short-run profit function model is referred to as the short-run model. By contrast, the long-run model consists of estimation results of the remaining terms of the profit function, and computation of the long-run supply and input demand equations, including demand equations for the quasi-fixed factors. In this chapter the results obtained by estimating the model developed in the previous chapter are reported.

First, estimation results from the short-run model are discussed. Second, these results are used to test the hypotheses presented in chapter I. Although the discussion focuses on the major hypothesis of the study concerning the apportioning of sources of output growth, the corollary hypotheses are tested as well. Third, the results obtained by estimating the long-run model are given. Fourth, the model is used to simulate the impact of alternative price policies on cereals and milk productions. Estimation and simulation results have several important policy implications that are discussed in the last section of this chapter.

VI.2. Short-run estimation results

In this section, the results obtained by estimating the short-run model (see V.2.2.) are given. This section begins with a general overview of the results. Then, the coefficients of the four output supply and three variable input equations are discussed, including own-price elasticities, cross-price elasticities, impact of quasi-fixed variables, impact of research and technology variables, impact of policy variables, and impact of other variables.

VI.2.1. Overview of the results

As discussed above, symmetry properties are a characteristic of any system of supply and demand equations derived from a profit function. Recall that symmetry can be expressed as the set of conditions:

$$\frac{\partial Q_i}{\partial P_{i'}} = \frac{\partial Q_{i'}}{\partial P_i}, \text{ if } Q_i \text{ and } Q_{i'} \text{ are both outputs or inputs or}$$

$$\frac{\partial Q_i}{\partial P_{i'}} = -\frac{\partial Q_{i'}}{\partial P_i}, \text{ if } Q_i \text{ or } Q_{i'} \text{ is an output and the other an input.}$$

In our model, since six equations are estimated, symmetry is represented by a set of fifteen restrictions. A joint F-test of these conditions yields a F-value of 1.69, which means that symmetry cannot be rejected for any significance level smaller than 0.075. Therefore, at the 5% level, symmetry cannot be rejected. The profit function framework is therefore adequate to analyze French agricultural production over the period of study. In everything that follows, symmetry is imposed.

The estimated results for the seven equations of the short-run model are contained in tables VI.1 and VI.2. The estimated coefficients are given in table VI.1. This table also shows two values of the goodness of fit coefficient, R^2. The estimation of the four output and two input equations by seemingly unrelated GLS (see V.5) is performed by stacking the equations and estimating them as one large equation. Consequently, the procedure does not yield measures of fit for the original equations, but only one measure for the global system. The system of the six equations is characterized by a R^2 of 0.9954, which is quite good even for time series. Measures of fit are obtained for each equation in the first stage of estimation. The R^2 of equations Q_C, Q_V, Q_M, Q_N, K_F, and K_H in that first stage are, respectively, 0.9903, 0.9279, 0.9908, 0.9865, 0.9814, and 0.9988. The final input equation, K_D, is estimated separately to determine the coefficients of the quasi-fixed and fixed factors that are not subject to symmetry conditions, as described in section V.2.3. The R^2 of this equation is 0.9549 which is also a satisfying result.

Elasticities computed at the data means as well as levels of significance of the estimated coefficients are presented in table VI.2. Each significance level is given by its p-value. This is the smallest level of significance for which the corresponding coefficient is statistically different from zero.

Recall that the first six equations are estimated using prices normalized by r_D. Consequently, the coefficients of r_D in these equations are computed using homogeneity restrictions. Obtaining their p-values requires computing their variances. Each of these coefficients is a linear combination of the coefficients of the six other price variables in the corresponding estimated equation (see equation V.6). Therefore, in each equation, the variance of the coefficient of r_D involves the variances of these six price coefficients and their fifteen covariances.

By symmetry, the value and variance of the coefficients on P_C, P_V, P_M, P_N, r_F, and r_L in the feeds equation are obtained from the value and variance of the coefficients of r_D in the corresponding equation. Lastly, the coefficient on r_D in the feeds equation is obtained by homogeneity. Its p-value is not computed. Obtaining the p-value requires computing the variance of b_{DD}, which involves all the variances and covariances between the six other price coefficients in the feeds equation. In turn, each of these coefficients is estimated as a linear combination of six other variables, since they are obtained by symmetry. Thus, the variance of b_{DD} involves the covariances between six linear combinations of six estimated coefficients, that is 540 covariances. Since the variance of the other coefficients in the feeds equation are high, with p-values greater than 0.30, the p-value of b_{DD} is also likely to be greater than 0.30.

For the directly estimated coefficients, imposing symmetry forces the coefficients involved to be equal in absolute value. In theory, the variances of these coefficients are also identical. Their estimated respective variances, however, are likely to be slightly different. This is due to rounding errors that accumulate since the results are obtained after several iterations. Generally, these rounding errors result in only small differences in the t-ratios, and resulting p-values.

As can be seen in the tables of results, not all of the technology and policy variables are present in all the equations. This is due to (1) assuming a-priori that some variables would not have an impact in specific equations, or (2) dropping some variables that did not show any statistical significance, in order to increase the number of degrees of freedoms and thus improve the significance levels of the remaining variables. The specific reasons for these omissions are explained at the appropriate time in the discussion that follows.

VI.2.2. Own-price elasticities

It is commonly hypothesized that output supply curves have positive own-price elasticities and that input demand curves have negative own-price elasticities. The results of the model generally conform to these a-priori hypotheses.

Table VI.1. Estimated coefficients from the short-run model

Explanatory Variable	Dependent variable Q_C	Q_V	Q_M	Q_N	K_F	K_H	K_D
Const.	-55137.1	-34394.2	-23883.9	-62411	-9905.8	-642.8	-31069.7
P_C	2878.1	-1265.9	1476.0	3417.4	750.25	62.60	4687.6
P_V	-1265.9	14651	-2117.3	-3833.0	117.6	7.192	7038.0
P_M	1476.0	-2117.3	4632.6	-697.5	1039.7	15.72	1956.5
P_N	3417.4	-3833.0	-697.5	-196.8	-1613.0	-71.95	1578.4
r_F	-750.2	-117.6	-1039.6	1613.0	-2622.0	153.1	657.0
r_H	-62.6	-7.19	-15.72	71.95	153.14	-12.39	-26.9
r_D	-4687.6	-7038.0	-1956.5	-1578.4	657.0	-26.9	-15459
L_A^F	7.49	10.86	2.91	16.56	3.85	0.26	-2.70
K_A^F	0.14	-0.21	0.17	0.51	0.27	0.0016	0.22
RES	0.075	0.044	0.0066	0.026	-0.0006	0.0004	-0.001
USP	3907.4	67365.8	13805.3	9233.2	-	-	-
CR	-5387.3	-	-2728.8	-3512.1	3968.5	-	8075.1
REM	-	-	-.31	1.47	-	-	-
CL	1.44	-1.09	-	-	-0.27	0.035	0.94
PL	-	-	0.67	1.10	-0.38	-0.018	0.71
DUM	-3010.6	-3959.8	-	-1143.8	-287.6	-	-
R^{2x}	0.9903	0.9279	0.9908	0.9865	0.9814	0.9988	0.9549^{xx}

R^2 for the system of Q_C, Q_V, Q_M, Q_N, K_F and K_H : 0.9954

^{x} Obtained in first-stage of GLS estimation except for equation K_D.

^{xx} Obtained from separate estimation fixing coefficients of output and input prices based on symmetry and homogeneity properties of the system of equations (see section V.2.2.).

Table VI.2. Estimated elasticities from the short-run model and significance levels of the estimated coefficients

Explanatory variable	Dependent variable Q_C	Q_V	Q_M	Q_N	K_F	K_H	K_D
P_C	**.34**	**-.05**	**.16**	**.11**	**.18**	**.17**	**.58**
	.22	*.62*	*.11*	*.15*	*.44*	*.25*	*.30*
P_V	**-.16**	**.66**	**-.24**	**-.13**	**.03**	**.02**	**.86**
	.63	*.02*	*.07*	*.32*	*.93*	*.87*	*.30*
P_M	**.18**	**-.09**	**.53**	**-.02**	**.26**	**.04**	**.25**
	.11	*.06*	*.0008*	*.56*	*.06*	*.65*	*.30*
P_N	**.40**	**-.16**	**-.007**	**-.006**	**-.38**	**-.19**	**.19**
	.12	*.27*	*.54*	*.95*	*.21*	*.19*	*.70*
r_F	**-.12**	**-.007**	**-.15**	**.07**	**-.88**	**.59**	**.10**
	.44	*.92*	*.06*	*.23*	*.03*	*.0003*	*.90*
r_H	**-.15**	**-.006**	**-.03**	**.04**	**.73**	**-.68**	**-.05**
	.29	*.88*	*.68*	*.26*	*.001*	*.005*	*.70*
r_D	**-.42**	**-.23**	**-.16**	**-.04**	**.12**	**-.06**	**-1.9**
	.30	*.30*	*.30*	*.70*	*.90*	*.70*	
L_A^F	**1.40**	**.73**	**.49**	**.87**	**1.47**	**.18**	**-0.70**
	.12	*.32*	*.09*	*.04*	*.16*	*.003*	*.60*
K_A^F	**.72**	**-.38**	**.80**	**.74**	**2.83**	**.19**	**1.5**
	.58	*.73*	*.09*	*.19*	*.07*	*.61*	*.38*
RES	**1.27**	**.27**	**.10**	**.12**	**-.02**	**.16**	**-.04**
	.0001	*.02*	*.07*	*.09*	*.88*	*.11*	*.92*
USP	**.31**	**1.92**	**.99**	**.20**	-	-	-
	.65	*.004*	*.02*	*.66*			
CR	**-.32**	-	**-.14**	**-.05**	**.48**	-	**.66**
	.05		*.05*	*.45*	*.02*		*.08*
REM	-	-	**-.19**	**.27**	-	-	-
			.55	*.49*			
CL	**2.27**	**-.62**	-	-	**-.87**	**1.28**	**2.04**
	.04	*.43*			*.54*	*.03*	*.02*
PL	-	-	**.75**	**.37**	**-.95**	**-.52**	**1.19**
			.002	*.12*	*.13*	*.07*	*.21*

Elasticities are given in bold typefaces, significance levels (p-values) are reported below the respective elasticities.

The estimated own-price elasticity of cereals supply is 0.34. This elasticity means that a 1 percent price increase would result in a 0.34 percent production increase, all else being constant. Thus, cereals supply appears to be inelastic in the short run. This is not surprising since, in the short-run, quasi-fixed variables do not have time to optimally adjust. Statistically, the short-run own-price elasticity for cereals is only marginally significant, since a test of the hypothesis that it is equal to zero would be rejected only for levels of significance greater than 0.22.

The estimated own-price elasticity of supply for crop products other than cereals is 0.66. Non-cereal crop production appears inelastic in the short run, although more price responsive than cereals production. This coefficient is statistically different from zero for any significance level greater than 0.02, and would thus be significant at most commonly used significance levels.

The estimated own-price elasticity of supply for milk is 0.53. Although inelastic, milk production appears fairly responsive to prices even in the short run. Given the adjustment constraints in the short-run, and the biological lags involved in milk production (it takes time to increase herd size), this is a relatively high elasticity. Statistically, this coefficient is different from zero for any level of significance greater than 0.0008.

The estimated own-price elasticity of supply for animal products other than milk is $-$ 0.006. Thus, as a group, animal products other than milk do not seem price responsive in the short run. The sign of the estimated coefficient is contrary to the hypothesis of positively sloped supply curves. However, this coefficient is not significantly different from zero for reasonable significance levels (p-value = 0.95).

On the input side, the own-price elasticity of demand for fertilizer and energy is -0.88. Since this elasticity appears close to -1.0, it is interesting to test whether or not it is statistically different from -1.0. Representing this elasticity by η_{FF}, the following test is performed:

$$H_0 : \eta_{FF} = -1.0$$

$$H_1 : \eta_{FF} \neq -1.0$$

Using the data means, this can be converted into a test of the corresponding coefficient:

$$H_0 : b_{FF} = -2965.81$$

$$H_1 : b_{FF} \neq -2965.81$$

The corresponding t-value is:

$$t = \frac{-2965.81 - (-2622.01)}{1032.257} = -0.33$$

At the 5 percent level of significance, the corresponding critical t-value is: $t_{12}^{.025} = 2.179$. Since $|t| < t_{12}^{.025}$, the null hypothesis cannot be rejected. Therefore, at the 5 percent significance level one does not reject the hypothesis that the demand of fertilizers and energy by the agricultural sector is unitary elastic in the short-run.

The own-price elasticity of the hired labor demand equation is $-$ 0.68. It has the hypothesized sign and reveals a moderately inelastic response. Its p-value is 0.005, so it is statistically different from zero at any chosen level of significance greater than 0.5 percent.

Finally, the own-price elasticity of the feeds demand equation is $-$ 1.9. This coefficient has the hypothesized sign, but reveals an input demand that is surprisingly elastic. As explained above, its p-value is not computed, because of the amount of computations that would be required, but its p-value is likely to be greater than 0.30 and thus statistically non-significant.

VI.2.3. Cross-price elasticities

Cross-price elasticities are discussed in three blocks: first, elasticities among outputs, second, elasticities between outputs and inputs, and third, elasticities among inputs. Because of symmetry, it was shown earlier that $\frac{\partial Q_i}{\partial P_{i'}} = \pm \frac{\partial Q_{i'}}{\partial P_i}$. Because this equality is between coefficients, it will not generally hold for the corresponding elasticities. In what follows, both elasticities are reported.

VI.2.3.1. Output-output elasticities

Some of the expected signs of the cross-price elasticities among outputs are not easy to hypothesize a-priori. To organize the discussion, each output equation is successively considered.

In the cereals equation, it is expected that the cross-price elasticity with the price of other crop products will be negative, since cereals and other crop products compete for land. This elasticity is found to be small (-0.16) and statistically not different from zero at any reasonable significance level. The cross-price elasticities between cereals and the prices of milk and of other animal products are difficult to hypothesize: on the one hand, they compete for inputs; on the other hand, cereals are used as an input for certain types of animal production (see the discussion in V.4.1.) These cross-price elasticities are estimated respectively to be 0.18 and 0.40, and are statistically different from zero for any significance level greater respectively than 0.11 and 0.12. Thus, cereals production does not appear to be affected much by the price of other crop products, but to positively respond to increases in the prices of milk and other animal products. Thus, the latter two products act as complements to cereal production.

Considering the supply of crop products other than cereals, we already know (by symmetry) that output is negatively related to cereals price, and that the coefficient is statistically not different from zero at any reasonable level of significance. The corresponding elasticity is $-$ 0.05, and it is not different from zero for any significance level smaller than 0.62. It is expected that the non-cereal crop products will behave as substitutes with respect to animal products, because they compete for resources without being used in large amounts for animal production. This is confirmed by the estimation results. The cross-price elasticities of non-cereal crop products with respect to prices of milk and other animal products are, respectively, -0.09 and -0.16. They are statistically different from zero for any significance level greater than, respectively, 0.06 and 0.27. Thus, non-cereal crop production does not respond much to cereals price, but it is negatively affected by increases in animal product prices. The later effects have statistical significance at usual levels only in the case of milk. Therefore, milk production acts as a substitute for non-cereal crop production, but the magnitude of the cross-price elasticity is small.

It has already been established that cereals and other crop products are respectively complements and substitutes for milk production. In the milk supply equation, the corresponding elasticities are respectively 0.16 and -0.24, with associated p-values 0.11 and 0.07. The other animal products are expected to be substitutes for milk, competing for the same resources. The corresponding elasticity is only $-$ 0.007, and it has a relatively high p-value of 0.54. Therefore, milk production is a complement to cereal production and a substitute for the other crop products but, surprisingly, does not respond much to the price of the other animal products.

From the above discussion, animal products other than milk act as complements with respect to cereals, as substitutes with respect to the other crop products, and are not affected greatly by milk prices. The corresponding elasticities in the animal products equation are respectively 0.11, -0.13 and -0.02, with associated p-values 0.15, 0.32 and 0.56. Only cereals price is marginally statistically significant, and even its impact is small.

VI.2.3.2. Output-input elasticities

The signs of the cross-price elasticities between outputs and inputs are theoretically unambiguous. In the supply equations, input prices are expected to have negative coefficients and, by symmetry, output prices are expected to have positive coefficients in the input equations. As was done above for the sake of clarity, these elasticities are discussed one equation at a time.

In the cereals equation, all three variable input coefficients have the expected signs. For fertilizer-energy, hired labor, and feeds, the elasticities are respectively −0.12, −0.15 and − 0.42. The associated p-values are 0.44, 0.29 and 0.30.[74] None of these is statistically different from zero at usual levels.

In the non-cereal crop equation, variable inputs produce results very similar to those in the cereals equation. Their coefficients all have the expected signs, but their significance levels are not high. For fertilizer-energy, hired labor, and feeds, the elasticities are respectively −0.007, − 0.006 and −0.23, and the associated p-values 0.92, 0.88, and 0.30.

A similar pattern holds for the milk equation. The same inputs have as respective elasticities −0.15, −0.03, and − 0.16, with p-values 0.06, 0.68, and 0.30. Thus, the input representing the aggregate of fertilizers and energy appears statistically significant at any level greater than 6 percent. This is somewhat surprising for the milk equation, where labor would have been expected to play more of a role than fertilizer and energy inputs.

In the animal product equation, supply elasticities with respect to fertilizer-energy, hired labor, and feeds, are respectively 0.07, 0.04, and −0.04, with corresponding p-values 0.23, 0.26, and 0.70.

[74] The variance for this coefficient is computed as explained above.

Although two of the input coefficients have the wrong sign, none of them appears to be significantly different from zero.

Because of symmetry, the conclusions drawn from the impact of input prices on output supplies will also apply to the impacts of output prices on input demands. Thus, in the fertilizer and energy input equation, demand elasticities with respect to prices of cereals, other crops, milk, and other animal products are respectively 0.18, 0.03, 0.26, and −0.38, with associated p-values 0.44, 0.93, 0.06, and 0.21. In the hired labor equation, the same elasticities (with p-values between parentheses) are respectively 0.17 (0.25), 0.02 (0.87), 0.04 (0.65), and −0.19 (0.19). The corresponding results for the feeds equation are 0.58 (0.30), 0.86 (0.30), 0.25 (0.30), and 0.19 (0.70). As could have been deduced from the above discussion, the only coefficient statistically different from zero is milk price in the fertilizer-energy equation, while cereals price is marginally significant in the hired labor equation, and the price of animal products (with the wrong sign) in the fertilizer-energy and hired labor equations. All other coefficients are not statistically significant.

In conclusion, input prices seem to have very little effect on agricultural output in the short-run. Although the sign of the impact is usually negative as expected, in most cases, tests of significance do not lead to the conclusion that the output-input cross elasticities are different from zero.

VI.2.3.3. Input-input elasticities

The input-input elasticities, i.e. the impact of an increase in the price of one input on the quantity demanded of another input, do not have signs that are easy to hypothesize. Theoretically, we expect to find at least two inputs behaving as substitutes toward each other.

In the demand equation for fertilizers and energy, the elasticities with respect to the prices of hired labor and of feeds are, respectively, 0.73 and 0.12, with associated p-values 0.001 and 0.90. Thus, hired labor and the aggregate fertilizer-energy are substitutes in French agricultural production. Since the price of feeds is not statistically significant in the equation, no conclusion can be reached concerning the relationship of these two inputs.

In the demand for hired labor, the coefficient of the fertilizer-energy price is positive, by symmetry. Its elasticity is 0.59, and its p-value 0.0003. The coefficient of the feeds price is negative, with an elasticity of -0.06, but non-significant (p-value is 0.70). Similar to the previous case, feeds and hired labor seem to behave as independent inputs in agricultural production.

Finally, in the last equation (the demand for feeds input) it is already known, by symmetry, that the coefficients of the two other input prices are statistically not different from zero. For the fertilizer-energy and labor inputs, elasticities are respectively 0.10 and -0.05, and the p-values 0.90 and 0.70.

In conclusion, several observations can be made from the cross-price effects. On the output side, some complementarity appears between cereals and the animal products (including milk). Non-cereal crops behave as substitutes for the animal products, but their expected substitution with cereals is not statistically significant. In the same way, substitution between milk and the other animal products did not turn out to be statistically significant. On the input side, hired labor and the aggregate input fertilizer-energy are clear substitutes. The last input, feeds, does not exhibit strong substitution possibilities with the other inputs.

VI.2.4. Impact of quasi-fixed variables

The two variables treated as quasi-fixed in this study are family labor and capital, the latter consisting of buildings and machinery.

First, an increase in the amount of family labor is expected to have a positive impact on production, as all inputs do. Even if the amount of labor in agriculture is not consistent with long-run optimal values, due to adjustment lags, it is expected that French agriculture has long passed the stage of zero marginal product of labor in agriculture that may characterize countries in early stages of development.[75], This is confirmed by the estimation results. The elasticities of cereals, other crop products, milk, and animal products with respect to family labor are respectively 1.40, 0.73, 0.49 and 0.87, with associated p-values 0.12, 0.32, 0.09 and 0.04. Thus, family labor has a significant and positive effect on all animal products. Labor impacts cereals production with an elasticity greater than one, which is rather surprising. This coefficient is marginally statistically different from zero. Family labor does not appear to have an appreciable impact on non-cereal crop production.

The signs of the relationships of family labor with the variable inputs are difficult to predict: since family labor is not a variable input, it cannot substitute easily for these inputs in the short run. The estimated demand elasticities of fertilizer-energy, hired labor, and feeds, related to the amount of fixed labor are respectively 1.47, 0.18, and − 0.70, with p-values 0.16, 0.003, and 0.60. Thus, the impact of family labor on feeds demand appears negative, but it is not statistically significant. Its impact on fertilizer and energy appears positive and very high, but is again only marginally statistically significant. On the other hand, the quantity of family labor has a positive and significant impact on the demand for hired labor, which probably reflects the impact of family labor on

[75] The extent of disequilibrium is empirically determined later.

labor-intensive products (milk and animal products): more family labor leads to increases in these products, which leads to increased demand for hired labor.

Second, the amount of quasi-fixed capital (buildings and machinery) is also expected to have a positive impact on production. For cereals, other crop products, milk, and other animal products, the respective elasticities are 0.72, -0.38, 0.80, and 0.74, with associated p-values 0.58, 0.73, 0.09 and 0.19. Thus, quasi-fixed capital does not show any significant impact on the crop production, but only on animal production. This impact is marginally significant in the case of non-milk products (test of significance rejected at any level smaller than 19 percent) but is statistically significant at the 0.09 level for milk, with an elasticity of 0.80. This suggests that increases in milk production in France have been due partly to capital intensification in the agricultural sector. This is discussed in greater length below.

As is the case for family labor, the impact of quasi-fixed capital on the demand for variable inputs is not easy to predict, except for the case of fertilizers and energy. These are capital-related inputs, and it is expected that they have complementary relationships with fixed capital, i.e., the latter has a positive sign in the corresponding demand equation. Estimated elasticities for fertilizer-energy, hired labor, and feeds are respectively 2.83, 0.19, and 1.50, with associated p-values 0.07, 0.61, and 0.38. The only impact with any statistical significance is on the demand for fertilizer and energy. The expected complementarity between these inputs and quasi-fixed capital comes out quite strongly.

VI.2.5. Impact of research and technology variables

The first variable used to capture technological change in the model is French public research expenditures. As explained in chapter III, research expenditures impact agricultural production over several periods of time, and this variable thus needs to enter the model with a lag structure. This poses some difficulty, since the data series available for research expenditures starts in 1959. Since degrees of freedom are already a problem, it is essential not to lose any more of them. In order to be able to incorporate research expenditures with a lag, the research series was extended back from 1959 by regressing it on a constant, a trend variable, and a dummy variable. Starting in 1970, research expenditures begin increasing at a faster pace; the dummy variable takes the value zero through 1969 and the value one from 1979 on. This equation has a very good fit (R^2 = .997). The values obtained for 1953 to 1958 are given in the data set, in appendix C. Because the confidence interval around the predicted values becomes wider as on moves away from the actual data points, it is desirable to use as small a number of predicted values as possible. On the other hand, it is desirable to fit as long a lag structure as possible, to avoid biasing the estimated coefficients of the lag structure. These two objectives are contradictory, and a middle ground must be taken. It was decided to use predicted data for the years 1955 to 1958, which constrains the lag to a five-year period. This is a much shorter lag on the effects of research expenditures than reported in some of the literature (see III.3.1.3.). However, much of the impact of research is likely to be captured by such a lag. Also, even though individual coefficients on specific lags will be biased, the sum of the coefficients is likely to be little affected by truncating the lag. This sum is the cumulative effect of interest in this study.

There are various ways to introduce lagged values of the research variable into the analysis. The most straightforward way is to make no assumption regarding the shape of the lag, and to then use current values of research expenditures as variables, as well as lags of one to five years of the same variable. This was done as a first approximation, but it added a great deal of collinearity to the data and used several degrees of freedom. Despite the collinearity problem, at least one of the lags appeared positive and significant in every output equation (except for non-cereals crop products). Thus, research expenditures appear to have a significant impact on most outputs. The problem is to find a way of measuring this impact without introducing strong multicollinearity into the analysis and using too many degrees of freedom.

One solution to this problem is to assume a-priori that the lags follow a particular distribution. For example, it can be assumed that the response is linear. The coefficient on lag i of the research variable is of the form $b_{t-i} = a_0 + a_1 i$ where a_0 and a_1 are constants to be estimated. By imposing the constraint $b_{t+1} = 0$, we are left with only one coefficient to estimate. The other coefficient is computed using the constraint, and the original b_{t-i} can then be computed.

Imposing such a lag structure did not give satisfactory results in our analysis. First, the coefficient a appears significant only in the cereals equation, despite the earlier significance of at least one research lag coefficient in the cereals, milk, and other animal products equations. Second, the symmetry conditions on the cross-price coefficients in the output supply and input demand equations are strongly rejected when this structure is imposed (p-value of the joint test is 0.01).

The lag response of the research variable can also be assumed to follow a quadratic structure. Quadratic lags are one of the most commonly imposed lags in empirical works. The coefficient on lag i is hypothesized to be of the form: $b_{t-1} = a_0 + a_1 i + a_2 i^2$ where a_0, a_1, and a_2 are coefficients to be estimated. Imposing the end-point constraint $b_{t+1} = 0$ reduces the number of coefficients to be estimated to two.

Imposing the quadratic lag structure with five lags maintains acceptance of the symmetry conditions in our analysis, but levels of significance of the coefficients of the research variables are very poor. In fact, they are almost never statistically significant, since only one of them has an associated p-value smaller than 0.15. In contrast, recall that several coefficients were significant when no structure was imposed. It is likely that the number of lags (five) is not sufficient to impose a quadratic lag. In any event, when a quadratic lag is imposed, the impact of research (evident when no structure is imposed) becomes statistically non-significant.

A third alternative for inclusion of the research variable consists of using only one lag for research expenditures in each equation. This alternative has the obvious benefit of saving degrees of freedom. The lag introduced in each equation is the one for which maximum effect was observed when no lag structure was imposed. The coefficient obtained is biased since all other lags are omitted. However, its estimate of the sum of coefficients is likely to present little bias, since it is as if the lag distribution were collapsed in a single year.

Pursuing this third alternative, research expenditures were lagged five periods for the cereals supply, the milk supply and the demand for fertilizers and energy; they were lagged four periods in the other equations. These correspond to the lag for which the impact was found to be greatest in the non-structured lag model, except for the case of milk. In this equation, the non-structured lag showed the strongest impact for the fourth lag. However, including this lag by itself in the milk equation resulted in a statistically non-significant impact (p-value = 0.15), whereas the non-structured lag exhibited one statistically significant coefficient. Including the fifth lag restores statistical significance of the coefficient on the research variable.

As mentioned earlier, the estimated marginal product of research is expected to be positive for all outputs, but could be positive or negative for the variable inputs, depending on whether technical change has been neutral, factor using, or factor saving. Estimated marginal products have a strong upward bias, due to the omission of private research, extension and education variables in the model.[76]

In the output equations, the estimated elasticities for public research expenditures are 1.27, 0.27, 0.10 and 0.12, respectively for cereals, other crop products, milk, and other animal products. The associated p-values are 0.0001, 0.02, 0.07 and 0.09. In each case, research expenditures have a positive and significant impact on production. The elasticity obtained in the cereal equation is high, which may reflect the upward bias mentioned above.

[76] To remedy this problem, Bredahl and Peterson divide the estimated marginal product by four. This is an arbitrary choice.

In the input equations, estimated elasticities for fertilizers and energy, hired labor, and feeds are respectively -0.02, 0.16, and -0.04 with corresponding p-values 0.88, 0.11, and 0.92. Thus, French research expenditures show little significant impact on input demands. The only case in which the level of significance might be expected to become acceptable with a larger data set is the demand equation for hired labor. Research expenditures do not seem to exhibit a strong bias toward purchased intermediate inputs that complement capital.

In conclusion, French public research expenditures show a positive and significant impact on every output production, being especially strong in the case of cereals. Research expenditures do not seem to have greatly affected the demands for variable inputs by the agricultural sector.

The other variable used to capture technological change in this study is a moving average of U.S. productivity (*USP*), chosen as a proxy for internationally available technology. A moving average takes into account the lags involved in technology transfers. Here, a five-year moving average was selected. Using a four- or six-year moving average does not greatly affect the results.

The U.S. productivity variable is not included in the input equations. When included, the p-values for the fertilizer-energy, hired labor, and feeds equation are respectively 0.61, 0.98 and 0.36. Omitting it improves the variances of many coefficients and theoretically adds no bias, since the dropped coefficients are statistically non-different from zero.

For the output equations, the supply elasticities of production of cereals, non-cereal crops, milk, and non-milk animal products with respect to *USP* are respectively 0.31, 1.92, 0.99, and 0.20, with associated p-values 0.65, 0.004, 0.02, and 0.65. These results show that international transfers of technology - as captured by *USP* - did not have a significant impact on cereals production or on the production of non-milk animal products. On the other hand, milk production and the production of non-cereal crop products appear to have been strongly influenced by technology transfers.

In conclusion, the variables used in this model to capture technological change did not show any statistically significant impact on the demand for variable inputs by the agricultural sector. However, the impact of technological change on output growth appears to have been quite significant over the period of study. French research expenditures have had an influence on the growth of all output categories, particularly strong in the case of cereals. The role of technology transfers was important for milk and non-cereals crop products. Comparisons of the respective roles of these variables are considered further in the following section about hypotheses testing.

VI.2.6. Impact of policy variables

As discussed in the previous chapter, four policy variables were considered in this study. The cumulative area of farmland consolidated under government programs is represented by *REM* . The yearly acreage sold by intervention agencies is captured by *SAF*, while *IVD* is the amount of retirement payments made to farmers, and *CR* represents the ratio of the average rate of farm loans to the market rate.

Only two variables appear in the final version of the model, *CR* and *REM* (see tables VI.1 and VI.2). The two other variables have been excluded, either because they tended not to be statistically significant or because their presence caused rejection of the symmetry conditions discussed earlier. This is explained at least partly by the collinear relationships in which these two variables are involved.

Multicollinearity can be detected using variance decomposition proportions.[77] Table VI.3 presents these multicollinearity diagnostics between all the variables of the model. Only the variance proportions corresponding to the eight smallest eigen-values are given. For all variables, this

[77] For a discussion of variance proportions as a diagnostic tool, see Myers p.221ff.

accounts for over 75 percent of the variance. The most severe almost-linear relationship associated with the smallest eigen value involves several variables. It is responsible for over fifty percent of the variance of milk price, fertilizer price, quasi-fixed capital, crop land, *REM* and *IVD* . Excluding one of these variables reduces this multicollinearity problem.

There were several reasons why *IVD* was a logical choice of the variable to drop. First, it never appears statistically significant, except in the fertilizer equation in which it would be significant at the 10 percent level. Second, the French economists we spoke with did not believe the *IVD* played much of a role. In fact, a study conducted by the French Ministry of Agriculture (Ministère de l'Agriculture) in 1979 concluded that *IVD* has had disappointing results, because the average age of the population was becoming younger, and because the amounts paid by *IVD* are insufficient to present a good enough incentive for retirement. This is corroborated by Klatzmann, who observes that, to keep the cost of the program within reasonable limits, retirement payments have been set so low that they probably did not have any significant influence on retirement decisions.

The next smallest eigen-value is associated with the other almost-linear relationship that exists between the variables of the model. This relationship involves mainly *SAF*, family labor and, to a lesser degree, crop land, labor wage and prices of crops products. The exclusion of *SAF* from the model thus reduces multicollinearity. If included, this variable would be statistically significant (at the 10 percent level) only in the milk and hired labor equations, and it would cause rejection of the symmetry conditions which are a theoretical requirement essential to our study.

The exclusion of the variables *SAF* and *IVD* should introduce only a very small bias in the other coefficients, because (1) their associated coefficients are statistically non-different from zero, in most cases, and (2) there is no reason to expect them to have high correlations with other variables in the model, since they represent policy decisions that have long-term orientations, not greatly influenced by annual quantities, prices or the other variables in the model. This is confirmed by looking at estimated correlation coefficients of these two variables with the rest of the variables in

Table VI.3. Collinearity diagnostics

Eigen-value	.0000001	.0000008	.00002	.00006	.0002	.0005	.0007	.0009
Intercept	.9903	.0006	.0051	.0035	.0001	.0003	.0000	.0000
P_C	.0499	.2320	.0552	.1574	.0000	.2032	.0579	.0032
P_V	.0254	.2040	.0732	.3280	.0477	.0251	.0682	.0078
P_M	.5235	.0009	.0642	.1185	.0026	.2259	.0336	.0161
P_N	.0935	.0807	.0571	.3781	.0014	.1399	.0052	.0521
r_F	.7103	.0046	.0394	.0265	.0176	.0168	.0004	.0665
r_H	.0872	.2428	.0029	.0000	.0435	.0071	.0220	.5164
L_A^F	.0471	.4628	.4157	.0213	.0208	.0104	.0172	.0043
K_A^F	.8330	.1588	.0003	.0066	.0000	.0009	.0001	.0000
RES	.1894	.0025	.1796	.1747	.0004	.2325	.1530	.0321
USP	.0833	.1144	.5151	.2741	.0001	.0105	.0004	.0001
CR	.1305	.1752	.0998	.0000	.0007	.0368	.4303	.0007
REM	.5837	.0984	.3001	.0130	.0007	.0010	.0009	.0011
SAF	.1507	.5888	.0253	.0662	.0490	.0041	.0025	.0597
IVD	.6802	.0948	.0008	.0165	.0004	.0597	.0152	.0400
CL	.7258	.2603	.0102	.0011	.0021	.0002	.0001	.0002
PL	.4289	.1758	.0702	.0072	.3074	.0014	.0041	.0039
DUM	.1104	.0418	.2188	.0630	.0130	.0014	.0017	.0264

the model. Only one correlation involving these variables is high: *CL* and *SAF* have an estimated correlation of −0.95. With time-series data, having only one such correlation is remarkable.

Recall that the variable *CR* represents the ratio of the average rate of farm loans (many given at preferential rates) to the market rate. Because of the severe degrees of freedom problem mentioned above, this variable is dropped from equations where (1) its coefficient is not statistically significant and (2) estimated values of the other coefficients are little affected by the presence of the variable. This is the case of *CR* in the non-cereals crop supply and the hired labor demand equations. If included in these equations, the estimated coefficients for *CR* have respective p-values of 0.36 and 0.29, while all other estimated coefficients show fairly similar values and keep their original sign. The greatest change occurs when the credit variable is added to the hired labor equation; the elasticity of hired labor with respect to the price of non-cereal crop products is multiplied by a factor of 2.7. As evidenced by table VI.2, the variable *CR* is also not statistically different from zero in the non-milk animal products equation. However, dropping *CR* from that equation drastically alters several coefficients. For example, the elasticity of milk production with respect to hired labor wage rate is divided by a factor of 11.2. Although this coefficient is not statistically significant, this is too large a change to be accepted. Therefore, the variable *CR* is kept in the non-milk animal products equation.

In the equations where the variable *CR* was kept, results obtained are better on the output side than on the input side. On the output side, the estimated elasticities of cereals, milk, and other animal products with respect to *CR* are respectively −0.32, − 0.14, and −0.05, with associated p-values 0.05, 0.05, and 0.45. Thus, a lowering of subsidized credit rates would result in a significant increase in cereals and milk production, and would not have much effect on the other products. On the input side, elasticities of the demands for fertilizers and energy and for feeds with respect to the variable *CR*, are respectively 0.48 and 0.66, with associated p-values 0.02 and 0.08. To understand what happens with these two inputs, recall that the variable *CR* is the ratio of the average rate of subsidized farm loans to the market rate. As was explained in chapter II (see

II.4.1.3), most short-term loans made by farmers are made at market rates. The coefficients on the variable *CR* in the two input equations reflect the relationship between the demand for these inputs and the loan market rate. When the market rate increases, the variable *CR* decreases, and so do the demands for feeds and for fertilizers and energy.[78]

The other policy variable used in the model is the cummulative area consolidated by the end of each year, under government programs, represented by *REM*. As shown in the tables of results, this variable enters only two equations, the supply for milk and animal products. Its coefficients in these two equations are not statistically significant, having p-values of 0.55 and 0.49, respectively. The variable *REM* was kept in these two supply equations since dropping it would considerably alter some other coefficients despite the fact that no bias should theoretically be introduced. It was dropped from the other equations because, statistically, it was not significantly different from zero and because dropping it did not substantially modify the size of the coefficients, while reducing their standard errors in several cases.

In conclusion, in the short-run, the only policy variable that had any impact on output production is the variable used to capture credit policies. The subsidized credit rates made available to farmers appear to have had a significant and positive impact on the production of cereals and milk. This is interesting as one recalls that these are, by far, the two main products of French agriculture.

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[78] Notice that the increase in output supplied associated with a decrease in *CR* could be due also to a rise in market rates, rather than a lowering of subsidized rates.

VI.2.7. Impact of land resources

Note that land, in this study, is represented by two variables: *CL* , the amount of cultivated land and *PL*, the amount of pasture land. It is assumed that only *CL* is an input for crop products, and that only *PL* is an input for animal products. Each variable will be discussed in turn.

First, the amount of crop land appears in the cereals equation and in the non-cereal crop equation with the respective elasticities 2.27 and − 0.62, and associated p-values 0.04 and 0.43. Surprisingly, the amount of crop land does not appear to influence production of non-cereal crops. On the other hand, its estimated coefficient is statistically significant in the cereals equation, and shows an unusually high elasticity of 2.27. The results in these two equations may indicate that some non-cereal crop land has been converted to cereals production over the period.

On the input side, the elasticities of fertilizer and energy, hired labor, and feeds, with respect to the area of crop land are − 0.87, 1.28, and 2.04, with associated p-values 0.54, 0.03, and 0.02. Thus, an increase in crop land area does not significantly impact the demand for fertilizers and energy, which is contrary to what was expected. On the other hand, an increase in crop land area has a significant and positive impact on the demand for both hired labor and feeds. In both cases, this impact appears to be elastic.

Second, the amount of pasture land appears in the milk and in the non-milk animal products equations, with respective elasticities 0.75 and 0.37 and associated p-values 0.002 and 0.12. As expected, the area of pasture land has a strong positive impact on milk production. Its impact on the supply of other animal products is only marginally statistically significant. This can be explained by the fact that this output is the aggregate of many products, a large number of which do not utilize pasture as an input.

On the input side, the elasticities of fertilizer and energy, hired labor, and feeds, with respect to the area of pasture land are -0.95, -0.52, and 1.19, with associated p-values 0.13, 0.07, and 0.21. An increase in the area of pasture land appears to cause a decrease in the demands for hired labor and for fertilizers and energy. This occurs because an increase in pasture land is made at the expense of crop land, and pasture land is less demanding than crop land in these two input categories. An increase in pasture land also appears to increase the demand for feeds, which may be explained by the fact that an increase in pasture land is probably accompanied by an increase in animal production. However, the estimated response is elastic, which seems unreasonable.

VI.2.8. Impact of weather and other variables

The next variable discussed in chapter V is weather. This variable behaved very poorly in the model, never being statistically significant (when included, all p-values were greater than 0.20), and causing rejection of the symmetry conditions (the global test had a p-value of 0.006). Very likely, these problems are due to inadequate data for the weather variable. As mentioned earlier, weather is measured as yearly deviations from normal rainfall. However, in agricultural production, yearly amount of rainfall is not as telling as the amount of rainfall in critical months. Yearly data were used because it is hard to pick critical months when dealing with the aggregate of several commodities.

Due to the above reasons, the variable *WEA* was dropped from the model. However, to capture the fact that 1976 was characterized by a very severe drought, this year was removed from the data set.

The last variable in the model is the dummy variable introduced to capture the changed conditions due to the disruptions arising from the first oil shock of 1973 and the subsequent drought of 1976. This variable is represented by *DUM* in table VI.1. On the output side, it appears to be negative and significant for cereals (p-value = 0.01), negative and marginally statistically significant for the other crop products (p-value = 0.13), and negative but statistically non-significant for the non-milk animal products (p-value = 0.30). It was dropped from the milk equation, showing a p-value of 0.78, and not greatly affecting the signs of the other coefficients when omitted. On the input side, the dummy variable appears only in the fertilizer and energy equation, with a p-value of 0.62. It was kept in the equation, since dropping it induced large changes in some coefficients. This was not the case in the two other input equations, hired labor and feeds, where it had respective p-values of 0.23 and 0.45, and it was therefore dropped from these two equations.

VI.2.9. Summary of short-run results

By and large, results from estimation of the short-run output supply and input demand equations conform to theoretical expectations. Own-price elasticities are compatible with upward-sloping supply curves and downward-sloping demand curves, in general. Most cross-price elasticities have the expected signs. On the output side, some complementarity appears between cereals and the animal products (including milk). Non-cereals crops behave as substitutes for the animal products, but their expected substitution with cereals is not statistically significant. In the same way, substitution between milk and the other animal products did not turn out to be statistically significant. On the input side, hired labor and the aggregate input fertilizer-energy are clear substitutes. The last input, feeds, does not exhibit strong substitution possibilities with the other inputs.

The impact of the quasi-fixed factors (labor and capital) on both outputs and inputs is positive in most cases, the exceptions being the impact of labor on the demand for feeds and the impact of capital on the supply of non-cereal crop products.

The variables used to capture technological change did not show any significant impact on the demand for variable inputs by the agricultural sector. However, the impact of technological change on output growth appears to have been quite significant over the period of study. French research expenditures have had an influence on the growth of all output categories, particularly strong in the case of cereals. The role of technology transfers was important for milk and non-cereals crop products.

On the policy side, the only variable that had any impact on output production is that used to capture credit policies. The subsidized credit rates made available to farmers appear to have had a significant and positive impact on the production of cereals and milk, the two main products of French agriculture.

The results obtained with the land variables indicate that cereals production is very responsive to the amount of cultivated land, and milk production to the amount of pasture land. The impact of cultivated land on non-cereals crop production was negative and non-significant, while the impact of pasture land on non-milk animal products was positive and marginally significant.

Finally, the dummy variable introduced to capture the changed conditions after 1976 appears to be negative and significant for cereals, negative and marginally significant for the other crop products, and non-significant otherwise.

VI.3. Hypothesis testing in the short run

In this section, the results presented above are used to test the hypotheses found in chapter I. The discussion focuses on the major hypothesis of this study, which is that the increase of agricultural production in France between 1960 and 1984 has been due more to the combined effect of research, education, and structural change in agriculture, than to price and market policies. Testing this hypothesis necessitates the apportioning of output growth into proportions due to the movements in each explanatory variable over the period of study. Then, the discussion turns to the corollary hypotheses presented in chapter I.

As mentioned earlier, cereals and milk are the two main products of French agriculture, as well as the products which the EC exports the most. Rather than considering agricultural production as a whole, determination of sources of output growth and hypothesis testing are carried out for these two main commodity groups. Before reporting these results, changes in each variable in the model over the 1960-1984 period are described.

VI.3.1. Historical changes in variables of the model

To prevent potential yearly fluctuations from influencing the results of the decomposition of sources of growth in cereals and milk production, the change in each variable is computed from the average of the three earlier years used in estimation, to the average of the last three years.[79] The two outputs of interest, cereals and milk, have increased in these twenty-five years by 192.6 and 50.7 percent, respectively. The evolution of the explanatory variables is given in table VI.4. Evolution is presented as the change in level and also as the percentage change.

In contrast with the spectacular output growth, the deflated prices of outputs have actually decreased over the study period. This is explained by the very high inflation prevalent in France during the time.[80] The same can be said for input prices, with the notable exception of the wage rate

[79] For the variables used contemporaneously, the change is from the average of the years 1960 to 1962 to the average of the years 1982 to 1984. For the variables that we lagged, these dates are adjusted accordingly.

[80] This is probably also due to increases in productivity which reduced costs, increased profits, and consequently increased production. This enabled EC policymakers to set intervention prices that fail to keep up with the general rate of inflation.

Table VI.4. Evolution of the explanatory variables over the period of study

Variable	Absolute change	Percentage change	Variable	Absolute change	Percentage change
Q_C	+ 11,349.92	+ 192.6%	Q_M	+ 4,883.64	+ 50.7%
P_C	-0.378	-31.85%	P_V	-0.054	-5.39%
P_M	-0.203	-18.14%	P_N	-0.249	-23.77%
r_F	-0.058	-4.33%	r_H	+ 17.57	+ 299.97%
r_D	-0.233	-20.55%			
K_A^F	+ 32,858.33	+ 83.44%	L_A^F	-1661.17	-55.18%
CL	-1331.93	-6.99%	PL	+ 772.9	+ 5.91%
CR	-0.189	-25.03%	REM	+ 8649.9	+ 294.48%
USP	+ 0.34	+ 45.18%	RES	+ 324,478.33	+ 698.34%

which increased by a factor of three in real terms in twenty-five years. As is the case for most developed countries, capital-labor substitution is evidenced by a fairly large increase in fixed capital and a concomitant decline in the amount of family labor. The quantity of land in production remains fairly stable, with a noticeable shift toward pasture land, perhaps encouraged by milk support prices.

On the technological side, the French effort in research is evidenced by the huge increase shown by the variable *RES*: real public research expenditures have increased by almost 700 percent in twenty-five years. Over the same period, U.S. productivity appears to have increased by 45 percent.

In terms of structural and credit policies, credit rates, as compared to market rates, were more favorable to farmers in 1982-1984 than in 1960-1962, as evidenced by the 25% decline in the variable *CR*, the ratio between the average loan rate received by farmers and the market rate. The consolidation policy (*REM*) has had some success, since the amount of land consolidated has been multiplied by three over the period.

VI.3.2. Sources of growth in cereals production

The decomposition of sources of growth in cereals production is shown in table VI.5. The computations explained earlier (see section V.4.1) are carried out, and their results reported both in levels and in percentage change. The first column of table VI.5 lists the explanatory variables. The second column presents the estimated impact of each of the explanatory variables, in levels.[81] The third column gives the percentage of the total estimated change in cereals output due to the movement of each explanatory variable over the period of study. The fourth column gives the percentage by which initial output is estimated to have increased due to the movement of each

[81] Recall that quantities are expressed as an index. For more details, see the discussion in V.4.1.

variable. Notice that this column sums to + 199.8 percent, while actual output growth was + 192.6 percent. Thus, the model slightly overestimates actual cereals output growth.

An examination of the results shows that technological change appears to have had a dominant impact on the growth of cereal output. Had everything else remained the same, French research expenditures would have caused cereals production to increase by 206.6 percent of the estimated increase, and technology transfers by an additional 11.3 percent. Together, these two variables account for almost 220 percent of the increase in cereals output. This is greater than 100 percent because the movement in other variables has had a negative impact on growth, as explained below. The impact of technological change is brought into perspective if we recall that estimated cereals production increased by 199.8 percent over the period. The results presented in the third column of table VI.5 show that, in twenty-five years, technological change would have induced estimated cereals production to grow by more than 400 percent. Even though this impact needs to be qualified by the upward bias present on the coefficients of the technological change variables, this is a very large impact.

The impact of price policies on cereals production, in contrast, appears to have been fairly minimal over the period. Although output prices increased substantially during the period, they were outpaced by inflation, and so declined in real terms. Consequently, price policies have not increased real prices, but have merely prevented them from falling to even lower market clearing levels. Since real prices of cereals declined, their contribution to output growth was negative. In fact, the decline in cereals price would have caused cereals production to decline by 18.5 percent, everything else being constant. The combined effect of changes in all output and input prices would have been a diminuation of cereals production of 36.3 percent. However, this does not tell the whole story about the impact of price policies, the real question being what would have happened if various price policies had not been in effect. This question is discussed below, when the estimated model is used to simulate the effects of various price policy scenarios.

Table VI.5. Estimated sources of cereals output growth

Explanatory variable	Impact in level	Percentage of estimated growth	Estimated percentage increase in output
P_C	-1087.9	-9.2%	-18.5%
P_V	+68.4	+0.6%	+1.2%
P_M	-299.6	-2.5%	-5.1%
P_N	-850.9	-7.2%	-14.4%
r_F	+43.5	+0.4%	+0.7%
r_H	-1099.9	-9.3%	-18.7%
r_D	+1,092.21	+9.3%	+18.5%
L_A^F	-12,442.2	-105.6%	-211.1%
K_A^F	+4600.2	+39.1%	+78.1%
RES	+24,335.9	+206.6%	+412.8%
USP	+1,328.5	+11.3%	+22.6%
CR	+1018.2	+8.6%	+17.3%
CL	-1918.0	-16.3%	-32.5%
DUM	-3010.6	-25.6%	-51.1%
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	+11,777.8	+100.0%	+199.8%

The effects of the quasi-fixed variables, labor and capital, on cereals growth counterbalance one another. Capital intensification, by itself, would have caused actual cereals production to grow by 78.1 percent. In contrast, the decline in family labor would have reduced output by 211.1 percent, everything else being constant. This, of course, is due to the positive marginal product of labor in cereals production. If taken together, the combined effect of capital intensification and migration of labor out of agriculture appears to be negative, which is not what was expected a-priori. This may be explained by the fact that much of the technological change is embodied in new capital, and these qualitative improvements in capital over time are not taken into account in the data used in this study. These qualitative differences are then probably attributed entirely to the technological change variables, French research expenditures and technological transfers. This may cause the coefficient on capital to be biased downward, and the coefficients on *RES* and *USP* to be biased upward.

Finally, on the policy side, it is to be noted that credit policies are responsible for an estimated 8.6 percent of the actual growth in cereals output. Everything else being constant, these policies would have increased cereals production by 17.3 percent which provides some justification for these policies.

In conclusion, cereals output in France over the period of study appears to have been driven mostly by technological change, largely induced by large research expenditures combined with a high marginal product of research for cereals production. Credit policies are seen to have played a modest role in output growth. The role of agricultural policies requires some simulation analysis, and will be discussed further.

VI.3.3. Sources of growth in milk production

The decomposition of sources of growth in milk production is given in table VI.6. The approach developed above for cereals production is followed here as well.

The second column of table VI.6 presents the estimated impact of all the explanatory variables in levels. In the third column, these impacts are computed as percentage of estimated growth. The fourth column gives the percentage by which initial output is estimated to have increased due to the movements of the explanatory variables. This column sums to 51.6 percent, while actual milk output growth was 50.7 percent over the period.

The results obtained for the milk equation show the same tendencies as those obtained for the cereals equation, with a few important differences. Technological change appears again to have played the major role in inducing production growth: if everything else had remained unchanged, the two variables capturing technological change would have caused milk production to increase by 71.0 percent, that is, by 137.5 percent of the estimated growth in production over the period. This is a very large impact, although it is relatively less than the overall impact of technological change on cereals production. Also, while the bulk of the impact was attributed to French research in the case of cereals, the results are somewhat different in the case of milk. Had nothing else changed, the results presented in table VI.6 suggest that French research expenditures would have been responsible for a 22.3 percent growth in milk production, while technology transfers would have accounted for a 48.7 percent growth. Thus, technology transfers account for 68.7 percent of the overall impact of technological change, and French research expenditures for the remaining 31.3 percent. It could be that transfers of technology required less adaptations to local conditions in the case of milk, since it is a production that does not depend as much on natural conditions (land, weather, etc.).

Table VI.6. Estimated sources of milk output growth

Explanatory variable	Impact in level	Percentage of estimated growth	Estimated percentage increase in output
P_C	-557.9	-11.2%	-5.8%
P_V	+114.3	+2.3%	+1.2%
P_M	-940.4	-18.9%	-9.8%
P_N	+173.7	+3.5%	+1.8%
r_F	+60.3	+1.2%	+0.6%
r_H	-276.2	-5.6%	-2.9%
r_D	+455.9	+9.2%	+4.7%
L_A^F	-4,834.0	-97.2%	-50.2%
K_A^F	+5,585.9	+112.4%	+58.0%
RES	+2,143.3	+43.1%	+22.3%
USP	+4,693.8	+94.4%	+48.7%
CR	+515.7	+10.4%	+5.4%
REM	-2,681.5	-54.0%	-27.8%
PL	+517.8	+10.4%	+5.4%
	------------	-----------	-----------
	+4970.7	+100.0%	+51.6%

As was the case for cereals, the movement of output and variable input prices did not have a strong impact on milk output growth. The decline in real milk prices by itself would have reduced milk production by 9.8 percent, while the combined effect of all output and input prices would have caused a diminution of production of 10.2 percent. However, these numbers do not say anything about the impact of price support policies. Determining this impact necessitates comparing the actual situation to what would have most likely prevailed in the absence of price supports. This is discussed below.

The combined effect of the quasi-fixed variables is in line with what was expected. Results show that migration of labor out of agriculture would be responsible for a 50.2 percent decline in milk production, other things being constant, while capital intensification would cause it to increase by 58.0 percent. The two movements interact with each other, capital substituting itself for labor. The net effect of this factor movement, in the short-run, has been to increase milk production by 7.8 percent, or 15.2 percent of the estimated output growth.

On the policy side, farm consolidation appears to have been detrimental to milk production, causing it to decrease by 27.8 percent over the period. This is not too surprising since consolidation would be expected to favor productions where land is an important input, i.e. all crops products. As was the case for cereals, credit policies have had an impact on the growth of milk production, causing it to increase by 5.4 percent, or 10.4 percent of the total growth.

In conclusion, the increases in cereals and milk production appear to have been due mostly to technological change. If no other forces had been present, technological change would have caused a production increase of 435.4 and 71.0 percent, respectively, for cereals and milk. This corresponds to 217.9 and 137.5 percent of the estimated increases in these products. These increases are attributed mostly to French research expenditures in the case of cereals. For milk production, however, the production increase due to technological change is attributed to both French research expenditures, for 31.3 percent, and to transfers of technology, for 68.7 percent. Credit policies have played a role in the growth of output production. Although their role is modest compared to the impact of technological change, credit policies are responsible for 8.6 and 10.4 percent of the estimated growth in cereals and milk outputs. The role of agricultural price policies can be determined only through simulation analysis, and will be discussed later. Let us now turn to the corollary hypotheses of the study.

VI.3.4. Tests of the corollary hypotheses

Recall that the first hypothesis stated in chapter I is that the increase in agricultural production resulting from changes in technical inputs can be attributed more to domestic research than to international transfers of technology, though the latter is hypothesized to have had a significant and positive influence. The coefficients of the two variables *RES* and *USP* in the cereals equation are estimated to have p-values of 0.0001 and 0.65 respectively (see table VI.2). Thus, technology transfers do not appear to have had a significant impact on cereals production, so that the second part of the first hypothesis is rejected in that case. The increase in cereals production resulting from changes in technical inputs is therefore attributed mostly to domestic research.

In the milk equation, both variables *RES* and *USP* are statistically significant (with respective p-values 0.07 and 0.02), and they explain respectively 31.3 and 68.7 percent of the technological change impact. Since both technology variables are significant in this equation, it is interesting to test whether or not their impacts on milk production are statistically different from each other. Following the notation in appendix B, b_{MR} and b_{MU} represent the marginal products, respectively, of the two variables *RES* and *USP* in the milk supply equation. The test of equality of these coefficients is performed as follows:

$$H_0 : b_{MR} - b_{MU} = 0$$

$$H_1 : b_{MR} - b_{MU} \neq 0$$

The value of the associated t-test is:

$$t = \frac{b_{MR} - b_{M\,U}}{\sigma_{MRU}},$$

where σ_{MRU} is the standard deviation of the expression $b_{MR} - b_{M\,U}$. It is computed as follows:

$$\begin{aligned}(\sigma_{MRU})^2 &= \mathrm{Var}(b_{MR} - b_{M\,U}) = \mathrm{Var}(b_{MR}) + \mathrm{Var}(b_{M\,U}) - 2\mathrm{Cov}(b_{MR}, b_{M\,U}) \\ &= 0.000011 + 26{,}386{,}616.92 - 2(3.8136) \\ &= 26{,}386{,}609.29\end{aligned}$$

Thus, the above t-value is:

$$t = \frac{0.006 - 13{,}805.3}{5{,}136.79} = -2.69$$

At the 5 percent level of significance, the corresponding critical t-value is $t_{13}^{.025} = 2.16$. Since $|t| > t_{13}^{.025}$, the null hypothesis is rejected. Therefore, at the 5 percent significance level, the impacts of the two technology variables on milk production are statistically different from each other.

In summary, contrary to what was found for the cereals equation, the first part of the first hypothesis (i.e., domestic research has had a greater impact than international transfers of technology) is rejected in the case of milk production, while the second part (that transfers of technology have had a significant and positive influence) is accepted.

The second hypothesis stated in chapter I is that French structural and credit policies have had a positive impact on both the level of resource utilization in agriculture and on the level of output. Since none of the structural variables used in the model appears significant in the estimated equations, this hypothesis is rejected for these variables. In the case of credit policies, the variable used was statistically significant for the cereals and milk equation (with p-values of 0.05 in both cases), with the hypothesized signs, but non-significant in the other two output equations. Thus, credit policies have had a positive impact on the production of cereals and milk. On the input side, the credit policy variable was non-significant in the hired labor equation, but significant in the fertilizer-energy and feeds equation, with respective p-values 0.02 and 0.08. Input demands were found to decrease when farm credit subsidies increase, but this was shown to be equivalent to an increase in the market loan rate in our study. Since preferential rates apply mostly to long-term loans, input demands are expected to respond to market loan rates, and the response is as anticipated.

The third hypothesis stated in the first chapter is that both labor and capital have had positive marginal products in French agriculture, so that labor migration out of agriculture has had by itself a negative impact on agricultural production while capital intensification has had a positive impact. The net effect of this substitution of capital for labor is hypothesized to have led to an increase in agricultural production. The results reported in table VI.2 indicate that family labor shows a positive marginal product for all output equations, significant in the case of milk and animal products, marginally significant for cereals, and non-significant for non-cereals crop products. Fixed capital was estimated to have an impact that was positive and significant on milk production, positive and marginally significant on the production of other animal products and non-significant on the production of all crops. The net effect of labor-capital substitution was found to be positive in the case of milk, and negative in the case of cereals production. The hypothesis is therefore accepted in the former case, and rejected in the later.

The fourth hypothesis stated in chapter I is that price support policies have had a direct positive impact on both the level of resource utilization in agriculture and the level of agricultural output. As shown in the results, the decline in real output prices would have caused a reduction in output production, everything else being constant. Yet, this price decline would have been much steeper without the price supports established by the European Community. To determine the impact of these price support policies, and thus test the fourth hypothesis, the actual growth of outputs must be compared to the growth predicted under alternative price scenarios. This is presented later in this chapter (see section V.5).

VI.4. Long-run estimation results

In this section, the results obtained by estimating the long-run model (see V.2.3.) are given. The section begins with a discussion of the choice of the approach followed to estimate the remaining terms of the profit function. Then, the estimated long-run output supply and input demand equations are discussed, including own-price elasticities, cross-price elasticities, impact of technological variables, impact of policy variables, and impact of land resources. The analysis of disequilibrium in the labor and capital markets closes this section.

VI.4.1. Estimation of the profit function

Recall from V.2.3 that the obtainment of long-run output supply and input demand equations requires the estimation of the entire profit function. Many of its coefficients were estimated as part of the short-run model. As given by equation V.10, the remaining equation to estimate is:

$$\begin{aligned} \Pi^{\Delta} = \; & \beta_o + \sum_j \mu_j Z_j + \sum_k \delta_k W_k + \frac{1}{2} \sum_j \sum_{j'} \gamma_{jj'} Z_j Z_{j'} \\ & + \frac{1}{2} \sum_k \sum_{k'} \chi_{kk'} W_k W_{k'} + \sum_j \sum_k \theta_{jk} Z_j W_k \end{aligned} \qquad (V.10)$$

where Π^{Δ} represents variable profits minus all the variables estimated in the short-run model times their respective coefficients, Z_j the two quasi-fixed factors, and W_k the ten fixed or exogenous variables that are described above. All the Greek letters are coefficients. As discussed in chapter V, the number of coefficients to be estimated is 1 for β_0, 2 for μ_j, 10 for δ_k, 3 for $\gamma_{jj'}$, 55 for $\chi_{kk'}$, and 20 for θ_{jk}. In all, this amounts to 91 coefficients. Since the available data set goes from 1959 to 1984, containing 26 observations, estimation of all the coefficients is impossible. Consequently, some assumptions must be made.

Two alternative sets of assumptions were used. In the first case, only the variables involving the quasi-fixed variables were kept in estimation of Π^{Δ}. In the second case, the set of variables present in Π^{Δ} is reduced to those that were the most important in the short run, i.e. the quasi-fixed variables and the variables used to capture technological change. The choice between those approaches will be made according to some theoretical expectations that are discussed next.

VI.4.1.1. Theoretical expectations

Recall that long-run output supply and input demand equations are obtained by substituting K_A^F and L_A^F by their optimal values -- as a function of all the exogenous variables -- in the corresponding short-run functions. Thus, the expressions giving the optimal values of K_A^F and L_A^F permeate the long-run results. As given by appendix B (B.5 and B.6), these expressions are:

$$K_A^{F^*} = a_{KK}\,[r_K - b_K - \sum_{\rho} b_{PK}\,P - \sum_{\zeta} b_{KW}\,W] + a_{KL}\,[r_L - b_L - \sum_{\rho} b_{PL}\,P - \sum_{\zeta} b_{LW}\,W] \qquad (B.5)$$

$$L_A^{F^*} = a_{LK}\,[r_K - b_K - \sum_{\rho} b_{PK}\,P - \sum_{\zeta} b_{KW}\,W] + a_{LL}\,[r_L - b_L - \sum_{\rho} b_{PL}\,P - \sum_{\zeta} b_{LW}\,W] \qquad (B.6)$$

where P represents a generic element of ρ, the set of output and variable input prices, W is a generic element of ζ, the set of non-price variables excluding the quasi-fixed factors, r_K and r_L are the opportunity costs, respectively, of capital and family labor, the b's are coefficients to estimate, and the a's are computed from estimated coefficients. From the above expressions, it appears that the four coefficients a_{KK}, a_{KL}, a_{LK}, and a_{LL} affect all the coefficients of $K_A^{F^*}$ and $L_A^{F^*}$ and, consequently, all the long-run supply and demand elasticities. From B.5 and B.6, these coefficients are:

$$a_{KK} = \frac{\partial K_A^{F^*}}{\partial r_K},\; a_{KL} = \frac{\partial K_A^{F^*}}{\partial r_L},\; a_{LK} = \frac{\partial L_A^{F^*}}{\partial r_K},\; \text{and } a_{LL} = \frac{\partial L_A^{F^*}}{\partial r_L}$$

In keeping with the assumptions of downward-sloping demand curves, and of substitution between capital and labor, theory predicts that a_{KK} and a_{LL} are negative, and a_{KL} and a_{LK} positive. We also expect own-price effects to dominate long-run effects, so that $|a_{KK}| > |a_{KL}|$ and $|a_{LL}| > |a_{LK}|$.

These assumptions restrict the signs and magnitudes of the coefficients on the variables $(K_A^F)^2$, $(L_A^F)^2$ and $K_A^F L_A^F$ in Π^Δ, represented respectively by $1/2b_{KK}$, $1/2b_{LL}$, and b_{KL} in keeping with the notation in appendix B. The computations performed in appendix B between B.4 and B.5 show that:

$$a_{KK} = \frac{b_{LL}}{\Delta},\ a_{KL} = a_{LK} = -\frac{b_{KL}}{\Delta},\ \text{and}\ a_{LL} = \frac{b_{KK}}{\Delta}$$

where $\Delta = b_{KK}b_{LL} - (b_{KL})^2$.

The sign of Δ can be determined, since we expect own-price effects to dominate cross-price effects. We can write:

$$\begin{aligned}\Delta &= b_{KK}b_{LL} - (b_{KL})^2 = \Delta a_{LL}\Delta a_{KK} - \Delta^2 a_{KL}a_{LK} \\ &= \Delta^2(a_{LL}a_{KK} - a_{KL}a_{LK})\end{aligned}$$

which is positive, since $|a_{KK}| > |a_{KL}|$ and $|a_{LL}| > |a_{LK}|$ Going back to the estimated coefficients, having $\Delta > 0$ implies that b_{LL}, b_{KL}, and b_{KK} should all be negative to satisfy the assumption of downward-sloping demand curves and substitution between capital and labor.

Since the a's affect all the coefficients of the lon-run supply and demand functions, the signs of b_{LL}, b_{KL}, and b_{KK} are critical for the validity of the long-run results. Consequently, these signs are used below to evaluate the two sets of assumptions made to estimate the coefficients of Π^Δ.

VI.4.1.2. Estimation under the first set of assumptions

In the first case it was assumed that all the fixed or exogenous variables (technological change, policy and other variables) do not directly influence variable profits, but influence them through their interactions with (1) the output and variable input prices, and (2) the level of quasi-fixed variables, labor and capital. The impact of the product of any two fixed or exogenous variables is also assumed to be very close to zero. The coefficients δ_k and $\chi_{kk'}$ are thus fixed to zero. It is important to notice that, despite reducing the number of coefficients to estimate, there are still a large number of coefficients to be potentially estimated in the profit function. In the output supply and input demand equations from the short-run model, 81 coefficients were estimated (see table VI.1), and here twenty-six coefficients are potentially left to be estimated. In all, 107 coefficients are estimated.

The profit equation remaining to be estimated with the above restriction comprises one constant term, two terms for the quasi-fixed factors, two terms for the squares of the quasi-fixed factors, one for their interaction, and twenty terms for the product of each of these quasi-fixed variables with the ten fixed or exogenous variables present in the model.[82] Thus, there are 26 coefficients to estimate, with a data set that goes from 1959 to 1984, with 26 observations. Two observations were lost, because several variables are lagged one period, and because of bad weather conditions in 1976, as explained in VI.2.8. In keeping with the discussion held in that section, the variable *WEA* is dropped from the model leaving us with 24 coefficients to estimate. Estimating 24 coefficients with 24 degrees of freedom is still impossible. The second assumption made is that the interaction terms involving the dummy variable would have very small coefficients, the effects of this variable being essentially captured in its interactions with output and input prices.[83] Fixing these two coefficients at zero makes estimation possible.

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[82] Recall that a list of the variables is found in table V.1.

[83] When added separately, the coefficients of these two variables have p-values of 0.78 and 0.75.

The equation was then estimated iteratively, setting to zero the coefficients that showed the highest p-value at the previous stage. Note that, in this variable selection process, it was decided that the variables associated with the coefficients $\gamma_{jj'}$ should be kept, since these coefficients are critical to the obtainment of long-run results.[84]

In the first equation estimated, the coefficients on the fixed factors (μ_j) had p-values of 0.85 for capital and 0.90 for labor, and these two coefficients were fixed at zero in the next stage. In that stage, three coefficients had p-values greater than 0.90 and were consequently fixed at zero in the following stage. In the third estimation, two more coefficients had p-values greater than 0.70, and were subsequently fixed at zero.

The final estimation results are given in table VI.7. All estimations were performed using ordinary least squares. The equation has an R^2 of 0.79. This is fairly low for time series, and is probably due to the high number of variables that were dropped from the equation. The global F-test for the equation has a p-value of 0.097 indicating that, as a group, the explanatory variables have a marginally statistically significant impact on the dependent variable.

Besides the intercept term and the three variables with coefficients $\gamma_{jj'}$, eleven variables remain in the equation. Interestingly, three of the four terms involving technological change variables appear as statistically significant. These are both interaction terms with French research expenditures, and the interaction term between U.S. productivity and capital. This may imply that technological change has a long-run impact on output supplies beyond its short-run impact, through its effects on optimal adjustments of the quasi-fixed factors. However, the coefficient on the interaction between quasi-fixed capital and technology transfers has a negative sign. As discussed in chapter V (see V.3.2) this is counter to a-priori expectations.

[84] This can be seen in the steps between equations B.4 and B.5 of appendix B.

Table VI.7. Estimated results of remaining terms of the profit function under the first set of assumptions

Variable	Coefficient	P-value
Constant	-33035.12	0.47
$(K_A^F)^2$	0.000052	0.24
$(L_A^F)^2$	0.029	0.17
$K_A^F\ L_A^F$	-0.0043	0.19
$L_A^F\ RES$	-0.00027	0.045
$K_A^F\ RES$	0.0000072	0.040
$K_A^F\ USP$	-1.66	0.077
$L_A^F\ SAF$	-0.00019	0.25
$K_A^F\ SAF$	0.0000077	0.26
$L_A^F\ REM$	0.030	0.10
$K_A^F\ REM$	-.00071	0.11
$L_A^F\ CR$	-56.94	0.041
$K_A^F\ CR$	1.50	0.091
$L_A^F\ IVD$	0.000034	0.062
$K_A^F\ CL$	0.00022	0.076

R^2 : 0.79

Going back to the discussion above, b_{KK} and b_{LL} are estimated to have positive signs, which does not conform to our expectations. It can also be noted that the product $b_{KK} \times b_{LL}$ is smaller than $(b_{KL})^2$, which is also contrary to the expectations formulated above. Notice, however, that the combination of $\Delta < 0$ and b_{KK} and b_{LL} positive will produce the correct signs for a_{LL} and a_{KK}, but these are obtained for all the wrong reasons. Since b_{KL} is negative, as expected, having $\Delta < 0$ will produce the wrong signs for a_{KL} and a_{LK}.

Thus, estimating the model under the first set of assumptions produced wrong signs and magnitudes on the critical coefficients b_{KK}, b_{LL}, and b_{KL}, indicating that the biases introduced were greater than we anticipated. On that basis, this set of assumptions is not appropriate, and different assumptions need to be made to estimate Π^{Δ}.

VI.4.1.3. Estimation under the second set of assumptions

In the second case, it was decided to keep in Π^{Δ} only the variables involving capital, family labor, French research expenditures, and U.S. productivity because these were the variables explaining most of cereals and milk output growth in the short run (see section VI.3). The implied assumption is that all the fixed or exogenous variables, apart from *RES* and *USP*, influence profits only through their interactions with output and variable input prices.

Except for the intercept and the three coefficients $\gamma_{jj'}$, eleven variables remain in the equation Π^{Δ}. The equation was estimated, but none of the variables appears significant probably because of the strong multicollinearity present between the variables. It was then decided to fix to zero the coefficients $\lambda_{kk'}$ remaining, i.e. the coefficients on $(RES)^2$, $(USP)^2$ and $RES\ USP$. That is to say, it was assumed that the technology variables potentially affect variable profits (1) directly, (2) through their interactions with output and variable input prices, and (3) through their interactions with the level of quasi-fixed variables.

Estimation of the equation with the remaining variables showed results very similar to the previous case, suggesting that collinearity relationships had not been removed from the variables. Only one coefficient, that associated with $(L_A^F)^2$, had an estimated p-value smaller than 0.20.

Since all variables had relatively close p-values, ranging from 0.30 to 0.50, it was difficult to make a selection based on that criteria. It was decided to drop, as a block, the two variables K_A^F and L_A^F , which only remain as interactions between variables. This was motivated by the fact that both variables had statistically non-significant coefficients in the estimation performed in VI.4.1.2.

The remaining equation was estimated. Significance levels were improved overall, but most remained greater than 0.20. It was then decided to drop either *RES* or *USP*, neither one being significant. In both cases, levels of significance improved, with the greatest improvement when *RES* was dropped. Also, when *RES* was dropped, all three coefficients b_{KK}, b_{LL}, and b_{KL}, had the hypothesized signs, while b_{KL} had the opposite signs when *USP* was dropped. For these reasons, it was decided to use the estimation results obtained by fixing to zero the coefficient of *RES*.

The final estimation results are given in table VI.8. Although the R^2 is only 0.60, fairly low for time series analysis, the global F-test for the equation has a p-value of 0.04. Thus, as a group, the remaining explanatory variables have a statistically significant impact on the dependent variable.

These results are used below to compute long-run supply and demand elasticities. Given the data limitations, they were obtained in a somewhat arbitrary fashion as is evident by the above description. Nevertheless, they are consistent with theoretical expectations, especially concerning the critical coefficients a_{KK}, a_{LL}, and a_{KL}.

The coefficients presented in table VI.8 were used in combination with those obtained from the short-run model to compute the long-run output supply and variable input demand functions.

Table VI.8. Estimated results of remaining terms of the profit function under the second set of assumptions

Variable	Coefficient	P-value
Constant	723,246.3	0.13
$(K_A^F)^2$	-0.0001046	0.10
$(L_A^F)^2$	-0.037326	0.07
$K_A^F \; L_A^F$	-0.0006045	0.67
$L_A^F \; RES$	-0.000213	0.007
$L_A^F \; USP$	267.40	0.16
$K_A^F \; RES$	0.0000061	0.006
$K_A^F \; USP$	16.18	0.16
USP	-1,616,113.3	0.14
R^2 : 0.60		

Computations were done following the approach outlined in chapter V, and detailed in appendix B. The results of these computations are given as elasticities in table VI.9.[85]

The long-run coefficients in table VI.9 are the sum of the corresponding short-run coefficients and of terms representing the additional impacts due to optimal adjustments of the quasi-fixed factors, labor and capital (see V.4.3). These additional terms are computed from coefficients estimated from both the short- and the long-run models. The process followed to compute these additional terms involves inverting a matrix of estimated coefficients (see appendix B, from B.4 to B.5), so that these terms are nonlinear combinations of estimated coefficients. Furthermore, the covariances between coefficients estimated from the short-run model and coefficients provided by estimation of the remaining terms of the profit function are not known. Therefore, the variances of the coefficients of the long-run output supply and variable input demand functions cannot be computed, and significance levels cannot be attached to these coefficients. Notice, however, that many coefficients estimated directly from the profit function (table VI.8) have good significance levels, four having p-values smaller than or equal to 0.10, and four more p-values smaller than 0.20. Consequently, it is likely that coefficients that are statistically significant in the short run remain significant in the long run. It is harder to hypothesize the long-run significance of coefficients that were not significant in the short run.

Another consequence of the way long-run coefficients are computed is that short- and long-run coefficients are the same for all the variables that do not appear in the final estimation of Π^{Δ}. This is the case for all the policy variables, for the variables representing land resources, and for the weather-related variables. Thus, the impacts of these variables on output supply and input demand equations are the same in the long run and in the short run. Their description is not repeated here.

[85] The quasi-fixed factors do not appear in table VI.8 since they have been replaced by their optimal values as a function of the other variables in the short-run model and their long-run opportunity costs, the industrial wage and the long-term interest rate.

Table VI.9. Computed elasticities for the long-run model

Explanatory Variables	Dependent variables Q_C	Q_V	Q_M	Q_N	K_F	K_H	K_D
P_C	0.43	-0.01	0.20	0.17	0.29	0.25	0.57
P_V	-0.04	0.75	-0.22	-0.07	0.09	0.14	1.09
P_M	0.23	-0.09	0.55	0.08	0.35	0.08	0.26
P_N	0.61	-0.08	0.02	0.14	-0.08	-0.04	0.27
r_F	-0.04	0.06	-0.11	0.13	-0.72	0.65	0.08
r_H	-0.08	0.03	-0.01	0.09	0.80	-0.63	0.01
r_D	-0.51	-0.37	-0.17	-0.07	0.10	0.01	-2.40
r_K	-0.00026	-0.00035	-0.00044	-0.00035	-0.0016	0.00004	-0.0011
r_L	-0.22	-0.13	-0.07	-0.13	-0.19	-0.19	0.14
RES	0.96	0.01	0.06	-0.03	-0.09	-0.15	-0.36
USP	2.85	2.46	2.48	2.09	4.86	1.72	0.74
CR	-0.32	-	-0.14	-0.05	0.48	-	0.66
REM	-	-	-0.19	0.27	-	-	-
CL	2.27	-0.62	-	-	-0.87	1.28	2.04
PL	-	-	0.75	0.37	-0.95	-0.52	1.19

VI.4.2. Own-price elasticities

It is commonly hypothesized that output supply curves have positive own-price elasticities and that input demand curves have negative own-price elasticities. In the short run, estimation results conformed to these hypotheses with the exception of the animal products supply curve which had a negative and non-significant own-price elasticity. It is also expected that both supply and demand curves are more elastic in the long run than in the short run, since some factor fixities are removed. The results of the model show marked differences between short- and long-run own-price elasticities, that usually conform to this theoretical expectation.

In the long run, the estimated own-price elasticity of cereals supply is 0.43. This represents a sizeable increase from the short run, where this elasticity is 0.34. Nevertheless, cereals supply remains inelastic even when labor and capital adjust to their optimal values. When this adjustment occurs, the estimated increase in elasticity due to capital adjustment is 0.006 and that due to labor adjustment is 0.085.[86] Thus, both effects are as theoretically expected. As mentioned earlier, it is not possible to compute the variance of the long-run coefficients.

The estimated long-run own-price elasticity for non-cereal crop products other than cereals is 0.75. This is compared with a short-run elasticity of 0.66. Thus, the optimal adjustment of quasi-fixed factors seems to have had some influence on the own-price elasticity of crop product supply. The two effects are as theoretically expected, since labor adjustments increase elasticity by 0.08, and capital adjustments by 0.01. However, recall that the coefficients on labor and especially capital are not statistically different from zero (respective p-values 0.32 and 0.73), so that this increase in output response is not likely to be statistically significant either.

[86] These impacts are computed as described in V.4.2.3.

In the milk supply equation, the estimated long-run own-price elasticity is 0.55, up from 0.53 in the short run. Both labor and capital adjustments increase the elasticity by about 0.01, with capital having a slightly stronger impact than labor. Both impacts are fairly small, so that most of the response of milk production to an increase in its own price occurs in the short run.

The estimated own-price elasticity of supply for animal products other than milk is 0.14 in the long run. In the short run, this elasticity is − 0.0006 and statistically non-significant. Optimal adjustments in labor and capital are estimated to increase the own-price elasticity of animal products by 0.11 and 0.03, respectively. These are the largest impacts observed thus far. In sum, these results suggest that an increase in the aggregate price of animal products other than milk will have an effect on production only after labor and capital have adjusted to their long-run equilibrium values.

On the input side, the long-run own-price elasticities of demand for fertilizer and energy, hired labor, and feeds are respectively − 0.72, − 0.63 and −2.40. These responses have the hypothesized signs, and differ from their short-run counterparts, which are respectively −0.88, −0.68, and −1.9. Except for hired labor, the optimal adjustment of quasi-fixed factors seems to significantly impact the own-price responsiveness of variable input demands, making it more elastic in the case of feeds and less elastic in the case of fertilizer and energy. This last case is contrary to expectations.

In conclusion, all own-price elasticities have the hypothesized sign in the long run. With but one exception, increases in any output price lead to greater output growth in the long run than in the short run because of positive additional impacts due to both capital and labor adjustments.

VI.4.3. Cross-price elasticities

As was done for the presentation of the short-run results, cross-price elasticities are discussed in three blocks: first, elasticities among outputs, second, elasticities between outputs and inputs, and third, elasticities among inputs.

VI.4.3.1. Output-output elasticities

It is expected that the relationships of substitutes or complements which were found among outputs in the short run still hold in the long run. Also, substitution is expected to be easier when all inputs can adjust to their equilibrium values. Therefore, positive cross-price elasticities are expected to increase in the long run. How complementary relationships are affected by optimal adjustments of the quasi-fixed factors is not clear a-priori.

In the short run, recall that cereal production does not appear to be greatly affected by the price of other crop products, but positively responds to increases in the price of milk and of the other animal products. In the long run, the cross-price elasticity of cereals supply with respect to the prices of other crops, milk, and other animal products are respectively − 0.04 , 0.23 and 0.61, which compares with − 0.16, 0.18, and 0.40 in the short run. Thus, the only substitute relationships involving cereals appear to be even weaker in the long run than in the short run. On the other hand, complementary relationships with both milk and other animal products are substantially strengthened when optimal factor adjustments occur. Since the coefficients of milk and animal products prices are statistically significant in the short run, they are likely to be significant also in the long run. The significance of the coefficient of the non-cereal crop products price is unclear, but its high p-value in the short run (0.63) makes it unlikely to become significant in the long run. Thus, even more than in the short run, milk and animal products act as complements to cereals production, and the substitute relationships between cereals and other crops appear very weak.

This weak substitutability also appears, by symmetry, in the supply of crop products other than cereals. Its long-run supply elasticity with respect to the price of cereals is -0.01, which compares to -0.05 in the short-run. It is not different from zero for any significance level smaller than 0.62 in the short run. Therefore, neither is it likely to be significantly different from zero in the long run. Non-cereal crop products are expected to act as substitutes with respect to animal products, because they compete for the same resources. In the long run, the cross-price elasticities of non-cereal crop products with respect to prices of milk and other animal products are, respectively -0.09 and -0.08. These elasticities are -0.09 and -0.16 in the short run. Comparisons of these results do not conform to our prior expectation that substitution would be easier in the long run, once labor and capital have adjusted. This may be due, at least partly, to the fact that labor and capital are considered perfectly mobile among the agricultural products in our models. Optimal adjustments concern the total quantity in the agricultural sector, but there is no provision in the model to allow for differentiation of capital or labor within the agricultural sector.

It has already been established that, in the long as well as in the short run, cereals and other crop products are respectively complements and substitutes for milk production. In the long-run milk supply equation, the corresponding elasticities are respectively 0.20 and -0.22, versus 0.16 and -0.24 in the short run. Although differences are small in the long run, they correspond to a strengthening of the complementary relationship and a weakening of the substitute relationship similar to what was observed above. In the long run, other animal products are estimated to become complements for milk production, with an elasticity of 0.02. The corresponding elasticity was -0.07 in the short run, with a p-value of 0.54. Again, in the long run, results indicate more complementarity between outputs.

The long-run supply elasticities for non-milk animal products with respect to cereals, other crops, and milk are respectively 0.17, -0.07, and 0.08, with short-run counterparts 0.11, -0.13, and -0.02. Once again, the trend toward more complementarity between outputs in the long run is confirmed.

This impact of long-run adjustment of the quasi-fixed factors on the complement/substitute relationships between outputs appears to be systematic. It can be understood given the structure of our model. When any output price increases, resources are drawn into the sector, which means increased capital investment in agriculture and reduced labor migration out of agriculture. Since labor and capital are assumed to be homogeneous within agriculture, the production of all outputs benefits from this increase in resources. Recall that, as mentioned above, all long-run effects can be shown to comprise a short-run effect and additional effects due to optimal adjustments of the quasi-fixed factors. From the discussion above, these additional effects are always positive when considering cross-elasticities between outputs, which explains why complementary relationships are strengthened and substitute relationships weakened in the long run.

VI.4.3.2 Output-input elasticities

In the long run, capital and labor become variable inputs and increase the substitution possibilities between inputs. The impact on output supply of an input price increase would thus be smaller in the long run than in the short run. Consequently, it is expected that the cross-price elasticities between outputs and inputs become less negative in the long run than in the short run. This outcome is generally confirmed by the results. In what follows, short-run elasticities are given in parentheses next to the long-run elasticities.

In the cereals supply equation, the long-run elasticities for fertilizer-energy, hired labor, and feeds, are respectively − 0.04 (−0.12), −0.08 (−0.15), and − 0.51 (−0.42). In the other crop supply equation, these elasticities are 0.06 (−0.007), 0.03 (−0.006), and −0.37 (−0.23). In the long-run milk supply equation, the same inputs have for respective elasticities −0.11 (−0.15), 0.01 (−0.03), and −0.17 (−0.16). In the animal product supply equation, these become 0.13 (0.07), 0.09 (0.04), and −0.07 (−0.04).

Thus, the only input price with a negative coefficient in all four supply equations is that of the feed input. This indicates that, even in the long run, this input is not easily substitutable. The coefficients of the two other input prices tend to become more positive in the long run, because of increased possibilities of substitution with the quasi-fixed inputs.

In the input demand equations, it is expected that all output prices will have positive coefficients. In all cases, the results conform to this theoretical expectation. It is harder to hypothesize on the relative size of these impacts in the long and the short run. On the one hand, because of increased possibilities of input substitution, an increase in output price can lead to input-output price elasticities smaller in the long run than in the short run. On the other hand, an increase in output price leads to more output growth in the long run than in the long run, which would lead to input-output elasticities larger in the long run than in the short run. Which effect will dominate is an empirical question.

In the fertilizer and energy demand equation, long-run elasticities with respect to the price of cereals, other crops, milk, and other animal products are respectively 0.29 (0.34), 0.09 (0.03), 0.35 (0.26), and $-$ 0.08 ($-$0.38), where the corresponding short-run elasticities are in parentheses. In the demand equation for hired labor, the same elasticities are 0.25 (0.17), 0.14 (0.02), 0.08 (0.04), and $-$ 0.04 ($-$0.19). For the feeds demand equation, these are 0.57 (0.58), 1.09 (0.80), 0.26 (0.25), and 0.27 (0.19). In most cases, elasticities are greater in the long run indicating that the increases in demand due to greater output production outweigh the reductions in demand due to greater input substitution possibilities.

In summary, elasticities between outputs and inputs differ between the short and long run. In the output supply equations, greater input substitutions in the long run make the input price elasticities less negative than in the short run. Also, greater output responses to output price increases lead to increased demands for all inputs, so that the demand elasticities of all variable inputs with respect to output prices are greater in the long run than in the short run.

VI.4.3.3. Input-input elasticities

In general, input-input elasticities do not have signs that are easy to hypothesize. From the discussion above, it is expected that the conclusions drawn from the short-run results still hold in the long run, i.e. that hired labor and the aggregate input fertilizer-energy are clear substitutes, and that the feeds input does not exhibit strong substitution possibilities with the other inputs.

In the equation for fertilizers and energy, the long-run elasticities with respect to the price of hired labor and feeds are respectively, 0.80 and 0.10. In the short run, the corresponding elasticities are 0.73 and 0.12 with respective p-values 0.001 and 0.90. The substitute relationships between fertilizer-energy and hired labor appears somewhat strengthened in the long run.

The elasticities of demand for hired labor with respect to fertilizer-energy and feeds are respectively 0.65 and 0.01 in the long run and 0.59 and -0.06 in the short-run. The latter have respective p-values of 0.0003 and 0.70.

In the feeds equation, the long-run elasticities with respect to fertilizer-energy and hired labor are respectively 0.08 and 0.01, compared to 0.10 and -0.05 in the short run. Since the short-run coefficients have respective p-values of 0.90 and 0.70, the long-run values are very unlikely to be statistically significant.

In summary, the substitute relationship between fertilizer-energy and hired labor appears strengthened in the long run. Cross-price elasticities involving the feeds input are small and very unlikely to be statistically significant.

VI.4.4. Impact of interest rate and industrial wage

In the long run, capital and family labor are treated as variable inputs. Thus, they appear in the output supply and input demand equations through their prices (or opportunity costs), instead of their levels.

The long-run supply elasticities of cereals, other crops, milk, and other animal products with respect to the interest rate are, respectively, −0.00026, −0.00035, − 0.00044, and −0.00035. These elasticities have the correct sign, but they are surprisingly small. The supply elasticities of the same outputs with respect to the industrial wage are, respectively, −0.22, −0.13, −0.07, and −0.13. They all have the hypothesized sign.

On the input side, no clear pattern emerges. The long-run elasticities of demand for fertilizer-energy with respect to interest rate and industrial wage are, respectively, −0.0016 and − 0.19 Both capital and family labor appear as complements to fertilizer-energy.

In the case of hired labor, long-run demand elasticities with respect to interest rate and industrial wage are, respectively, 0.00004 and − 0.19. Thus, capital appears to be somewhat substitutable to hired labor, but family labor and hired labor appear to act as complements. This is not too surprising since the qualifications -- and, consequently, the role -- of the two types of labor are quite different.

In the feeds equation, the long-run elasticities with respect to interest rate and industrial wage are, respectively, −0.0011 and 0.14. Family labor appears to be a substitute for feeds in the long run, which is a surprising result.

VI.4.5. Impact of technological variables

The first variable used to capture technological change in the model is French public agricultural research expenditures. In order to maintain consistency with the short-run estimation, and because of our limited number of degrees of freedom, research is represented by only one variable, i.e. research expenditures lagged five years. The estimated coefficient is likely to present little bias, since it represents the sum of the impacts of research over time (see VI.2.5). Interaction terms of this variable with labor and capital appear as statistically significant (see table V.8), so that optimal adjustment of these factors will have an impact on the marginal product of research.

It is expected that the marginal product of research be positive for all outputs, and larger when quasi-fixities disappear than when they are imposed, i.e. the long-run elasticities are expected to be larger than their short-run counterparts. For any input, the impact of research is also expected to be greater in absolute value in the long run than in the short run, whether or not technical change has been neutral, saving, or using toward that particular input.

The results obtained by the model do not seem to conform to these expectations. In the output equations, the estimated elasticities for public research expenditures in the long (short) run are 0.96 (1.27), 0.01 (0.27), 0.06 (0.10), and −0.03 (0.12), respectively for cereals, other crop products, milk, and other animal products. In all cases but one, these long-run elasticities are smaller than their short-run counterparts.

To understand what may be causing these theoretically unexpected results, it is useful to decompose the long-run effects, as presented in chapter V. Using cereals as an example, it was shown in section V.4.2.1. that the long-run impact of French research on any output supply could be decomposed into three parts. The first part represents the short-run (quasi-fixed factors fixed) impact, and the second and third capture additional impacts due to full adjustments in the capital and labor markets. These decompositions are given in table VI.10.

For each output supply equation, table VI.10 presents the short-run elasticity with respect to French public agricultural research, and the additional effects (given as elasticities) due to optimal capital and labor adjustments. As discussed earlier, all short-run elasticities have the hypothesized positive term. In the long run, it was expected to find a positive additional impact due to capital adjustments, while the additional impact due to labor adjustment is likely to be negative, but could be positive as well (see discussion in V.4.2.1.). Here, French research expenditures are estimated to increase the optimal values of capital in the agricultural sector, which yields positive additional output supply elasticities with respect to research. The exception of non-cereal crop products is due to the negative sign of capital in the corresponding short-run supply equation. French research expenditures are also estimated to decrease optimal values of family labor in the long run, which has a negative effect on the output supply elasticities with respect to research. The direction of these two effects conforms to prior expectations, but their relative size does not. Technological change was expected to be labor-saving and capital-using, which is what we find. However, it was also expected to find the capital impact to be larger than the labor impact, so that the net impact would be an increase in output. In our results, the negative impact due to decreased labor in agriculture outweighs the positive impact due to increased capital. This is why long-run output supply elasticities are smaller than their short-run counterparts.

The unexpected relative magnitude of these two impacts can be traced back to the estimated coefficients of the variables representing interaction terms between research and the quasi-fixed factors in the profit function. As described in chapter V, the impact of research on the long-run values of capital and labor is:

Table VI.10. Long-run elasticities of output supplies with respect to French research

	$Q^{\bullet}_C$	$Q^{\bullet}_V$	$Q^{\bullet}_M$	$Q^{\bullet}_N$
Short-run elasticity	+ 1.27	+ 0.27	+ 0.10	+ 0.12
Additional elasticity due to capital adjustments	+ 0.09	-0.05	+ 0.10	+ 0.09
Additional elasticity due to labor adjustments	-0.40	-0.21	-0.14	-0.24
Long-run elasticity	+ 0.96	+ 0.01	+ 0.06	-0.03

$$\frac{\partial K_A^{F^*}}{\partial R} = -a_{KK}\, b_{KR} - a_{KL}\, b_{LR}$$

$$\frac{\partial L_A^{F^*}}{\partial R} = -a_{LK}\, b_{KR} - a_{LL}\, b_{LR}$$

where b_{KR} and b_{LR} are the coefficients in the profit function of the product of research with capital and labor, respectively, and a_{KK}, a_{KL}, a_{LK} and a_{LL} are computed as shown in appendix B. In our model, a_{KK} is negative, a_{KL} positive, b_{KR} positive and b_{LR} negative (see table VI.8). Thus, these coefficients indicate that research expenditures tend to increase capital stock directly through the term in b_{KR}, and also to decrease optimal labor values, which has an added positive impact on capital because of substitution of these inputs in the long run. This is captured by the second term in $\frac{\partial K_A^{F^*}}{\partial R}$, which is also positive. Opposite conclusions could be obtained for the term $\frac{\partial L_A^{F^*}}{\partial R}$: both terms are negative. The estimated b_{LR} is sufficiently larger than the estimated b_{KR} that the negative terms dominate the comparison of long-run to short-run effects. That is, the estimated coefficients b_{KR} and b_{LR} have the hypothesized signs, but their relative magnitude does not conform to the a-priori expectations of output increases due to technological change being larger in the long run than in the short run. It is quite possible that these estimated coefficients have been biased by the variable selection process that was necessary to estimate the profit function.[87] Had we been able to keep more variables in the equation, their relative size may have been different.

For similar reasons, the same pattern holds on the input demands side. The long-run (short-run) elasticities of demand for fertilizers and energy, hired labor, and feeds with respect to French research expenditures are respectively -0.09 (-0.02), -0.15 (0.16), and -0.36 (-0.04).

The U.S. productivity variable, used as a proxy for internationally available research, exhibits long-run results that are quite different from those obtained with the French research variable. The

[87] In general, this could also be due to inflated variances due to multicollinearity. However, collinearity diagnostics on the variables of the profit function indicate that the two variables in question are not involved in any serious linear relationships.

long-run (short-run) supply elasticities for cereals, other crop products, milk, and other animal products with respect to that variable are, respectively, 2.85 (0.31), 2.46 (1.92), 2.48 (0.99), and 2.09 (0.20). The long-run elasticities are greater than the short-run elasticities, as expected a priori. The additional impacts of labor and capital adjustment on these elasticities both appear to be positive in all cases, which is contrary to our expectations. As indicated in table VI.8, this variable enters the profit function through its interaction terms with both capital and labor, beyond its interaction terms with output prices that were estimated as part of the short-run model. As was the case for the research variable, the coefficient on the interaction term with capital needs to be positive in order to capture the direct positive impact of the productivity variable on optimal values of capital. Our results conform to that requirement. By contrast, the sign of the estimated coefficient of the interaction term between *USP* and family labor is positive, while it was expected to be negative. Performing the same exercise as above, we would find that *USP* is estimated to increase both capital use and family labor in agriculture, which is a very unlikely result.

For the same reasons, the impacts of U.S. productivity on input demands due to optimal capital and labor adjustments are also positive. These terms are the only components of the corresponding long-run demand elasticities, since the variable was not present in the final version of the short-run model. Consequently, long-run demand elasticities with respect to U.S. productivity are positive. These elasticities are 4.86, 1.72, and 0.74 respectively for the demands for fertilizer-energy, hired labor, and feeds by the agricultural sector.

Another important result that comes out of the long-run model concerns the amount of disequilibrium in the capital and labor markets, and its consequences on output growth. This is the topic of the next section.

VI.4.6. Disequilibriums in the labor and capital markets

The comparison of the long run and the short run revolves around the use of quasi-fixed capital and labor in agriculture. In this section, long-run equilibrium quantities of labor and capital, given output and input prices and the values of the fixed factors, are discussed relative to their actual values. Production of cereals and milk under optimal conditions are also computed from the model. This provides an estimation of the growth potential of French agricultural production, under the actual conditions of technological change and price policies.

Given the output and input prices and values of the fixed factors, the long-run equilibrium values of labor and capital are computed analytically by the model to derive the long-run output supply and input demand elasticities that are discussed above. These expressions for optimal labor and capital can be used also to compute the optimal amount of labor and the optimal capital stock in agriculture, at each point in time. The formulas used for computation can be found in appendix B, as equations B.5 and B.6.

The results of these computations are presented in table VI.11. The first two columns present the actual and optimal values of capital, in millions of 1970 francs. The last two columns represent the actual and optimal values for family labor, in thousand workers.

As can be seen from table VI.11, the estimated optimal values for labor and capital vary in the same direction as the actual series, but with a smaller amplitude. Capital in agriculture is estimated to have been below optimal over the entire period of study. Disequilibrium was fairly strong early in the period, with actual capital values averaging 71 percent of the optimal values between 1960 and 1962. The amount of disequilibrium decreased over time, and actual values averaged 79.1 percent of optimal values over the period 1982 to 1984. Thus, according to our estimation results, French agriculture appears under-capitalized over the period of study. It is to be kept in mind that

Table VI.11. Actual and optimal values of quasi-fixed factors

Year	Capital values Actual	Capital values Optimal	Labor values Actual	Labor values Optimal
1960	38,224	53,647	3,084	2,447
1961	39,110	55,745	3,011	2,447
1962	40,803	57,473	2,937	2,455
1963	41,986	59,033	2,863	2,501
1964	43,616	60,639	2,789	2,508
1965	45,468	61,991	2,716	2,476
1966	47,428	63,616	2,642	2,475
1967	49,719	65,077	2,568	2,438
1968	51,895	66,891	2,464	2,365
1969	53,845	68,691	2,320	2,276
1970	56,208	69,686	2,100	2,293
1971	58,011	71,188	2,031	2,183
1972	59,392	73,883	1,954	2,137
1973	61,514	75,967	1,843	2,137
1974	63,694	77,271	1,770	2,204
1975	66,082	76,476	1,651	2,244
1977	68,248	80,068	1,574	2,172
1978	68,910	81,465	1,540	2,146
1979	69,914	83,153	1,504	2,115
1980	70,799	86,440	1,478	2,121
1981	71,294	86,348	1,441	2,135
1982	71,646	89,418	1,390	2,183
1983	72,374	92,013	1,349	2,210
1984	72,692	92,545	1,309	2,071

these results are obtained at prevailing actual prices. These results indicate that, given the price supports maintained over the period of study, even more capital will be drawn into the agricultural sector to obtain equilibrium over time. This does not rule out the possibility that, were price supports removed, there may be excess capital in the agricultural sector.

The results obtained in the labor market are somewhat more surprising. In the beginning of the period of study, our model suggests that there was excess labor in agriculture, which conforms to our expectations. Between 1960 and 1962, there was an average of slightly more than three million workers (3,011 thousand) qualifying as family labor in the agricultural sector. At the same time, the estimated optimal farm family population was only 2,450 thousand, that is, 81.4 percent of the actual number. Over time, the estimated optimal farm population decreased, but actual values decreased at an even faster pace, which is contrary to our expectations. Starting in 1970, actual values became smaller than optimal values. Eventually, actual family labor in agriculture averaged only 62.6 percent of our estimated optimal values between 1982 and 1984. The relative evolution of the two labor series is surprising since it is not consistent with the hypothesis of adjustment costs in the labor market. In fact, these results would indicate negative adjustment costs, which is very unlikely to occur. It is difficult to know why these results were obtained, since many estimated coefficients are involved in the computation of the long-run capital and labor series. Earlier, we had found evidence that some coefficients are biased, which may very well cause the unlikely results that are obtained here for the optimal labor series. Also, these results might be influenced by the price supports.

The long-run model also provides an estimation of output growth were capital and labor to have adjusted to their optimal values each year. Table VI.12 provides a comparison of the estimated cereals and milk production in the short run (capital and family labor at actual values), and the long run (capital and family labor at optimal values). In the early years of the study, cereals production appears greater in the short run than in the long run. This can be explained by the results above. In the earlier years, there is excess labor and insufficient capital in the sector, compared to optimal values. Because cereals production is estimated to be more elastic with respect to labor than capital (respective elasticities 1.40 and 0.72), the impact of labor dominates and causes cereals production to be smaller in the long run than in the short run. After four years, long-run production becomes larger than its short-run counterpart. The difference between the two series increases when both capital and labor are estimated to be in sub-optimal amounts in agriculture. In the years 1982-1984, it is estimated that cereals production would increase by 52.9 percent if optimal adjustments of capital and family labor occurred.

For milk production, estimated long-run values are consistently higher than those of the short-run. This is true even in the early years because, contrary to the cereals situation, milk production was estimated to be more elastic with respect to capital (0.80) than to labor (0.49). The larger disequilibrium in the capital market is compounded by the larger elasticity, and causes the observed results. In the years 1960-1962, it is estimated that milk production could increase by an extra 1.1 percent if labor and capital were at their optimal values. In the years 1982-1984, this proportion becomes 36.8 percent.

VI.4.7. Summary of long-run results

In conclusion, the long-run results of the model must be evaluated with caution because of the arbitrary process that was followed to estimate the remaining terms of the profit function (Π^{Δ}). Nevertheless, some key differences appear between those results obtained with long-run assumptions (quasi-fixed factors adjust to their optimal values) and those obtained with short-run conditions (quasi-fixed factors take on their actual values). First, output supply curves appear more elastic in the long run than in the short run which conforms to theory. However, own-price supply elasticities remain substantially smaller than one.

Table VI.12. Estimated cereals and milk production in the short and long run

Year	Estimated Cereals Production		Estimated Milk Production	
	Short Run	Long Run	Short Run	Long Run
1960	6366.8	3388.7	9724.1	9623.8
1961	5823.3	3093.6	9802.0	9917.6
1962	6308.1	4043.5	9919.4	10229.8
1963	6938.1	5896.5	10302.0	11205.8
1964	7062.4	6802.5	10864.1	12086.9
1965	7451.9	7527.9	11388.7	12653.1
1966	7474.7	8121.8	11473.5	12913.1
1967	8995.3	9903.4	12191.5	13654.7
1968	9934.9	11009.5	12694.6	14131.8
1969	11013.7	12691.9	12540.6	14232.7
1970	10023.1	13201.2	12033.3	14125.5
1971	11981.0	14800.9	12550.4	14507.1
1972	13495.4	16881.7	13080.6	15472.5
1973	13832.0	17539.0	12662.3	15106.5
1974	13899.7	18483.6	12315.7	14947.2
1975	12525.0	18412.5	12668.0	15574.2
1977	12454.8	18488.4	12875.4	16036.1
1978	13983.6	20671.5	13056.8	16628.5
1979	14713.4	21735.5	13412.5	17242.9
1980	16179.4	23928.0	14566.8	18935.2
1981	15120.3	23081.3	14405.6	18784.1
1982	16400.3	25578.1	14707.2	19859.7
1983	17657.0	27542.9	15066.5	20764.4
1984	19438.3	28659.4	14618.6	20102.7

Second, it was expected that the full impact of technological change on output would be felt only in the long run, when family labor and capital stock adjust to their equilibrium values. The results obtained did not entirely conform to this expectation. As discussed earlier, this is explained by a wrong sign on the estimated coefficient of the interaction term between *USP* and family labor, and a by correct sign but biased values on the terms involving French agricultural public expenditures. It is likely that the large number of variables that had to be dropped to estimate the long-run model introduced some bias, which is reflected in at least these three coefficients.

Lastly, capital in agriculture is estimated to have been below optimal over the entire period of study. In contrast, our model suggests that there was excess labor in agriculture in the beginning of the period of study, but that labor was below optimal at the end of the period. These results do not rule out the possibility that, were price supports removed, there may be excess capital and excess labor in the agricultural sector.

VI.5. Simulated impact of price policies

As was mentioned earlier, real prices of agricultural outputs have declined in France over the period of study, despite price supports by the European Community. Everything else being constant, this decline in real prices would have caused agricultural production to decrease, by 18.5 and 9.8 percent respectively for cereals and milk (see VI.3). The declines in production would have been even greater without the EC price support schemes, since supply curves are estimated to have positive own-price elasticities. The extent of these declines is estimated in this section under different price regime scenarios.

The impact of price supports on cereals and milk production could be determined if we knew what prices would have been without the price supports and associated trade policies (i.e. variable levies). If these policies were eliminated, market prices in France would be equal to world prices. France being a sizeable exporter, world prices would be somewhat higher than they are in the presence of these policies. How much world prices would increase is difficult to determine precisely, and which price represents the true world price is a somewhat arbitrary decision anyway. In order to have meaningful comparisons, it was chosen here to use U.S. prices as a base of comparison, so as to estimate what would have happened to French cereals and milk production had French prices been the same as U.S. prices.[88] A second set of simulations will evaluate the impact on cereals and milk of an overall decrease in European support prices.

All simulations are made assuming everything else remains the same. In particular, family labor and capital use in agriculture are assumed to be at their historical values. Consequently, the coefficients used in the simulations are those estimated in the short-run model. Before presenting the results, data sources and problems associated with data comparisons between France and the U.S. are discussed.

VI.5.1. U.S. prices used in the simulations

The series used for U.S. prices are the prices received by farmers, and come from the Commodity Yearbooks published by the Commodity Research Bureau. Because France and the U.S. do not report data in the same units, adjustments had to be made.

For cereals, U.S. prices are reported in dollars per bushel. On the other hand, French data are in francs per "quintal", one "quintal" representing 100 kilos. For each of the major cereals produced in France -- wheat, barley, corn and oats -- U.S. production was converted into dollars per

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[88] Since this study was stimulated by a policy debate mainly between France and the U.S., this comparison is all the more interesting.

pound.[89] An aggregate cereals price was then obtained by using the weights used earlier to aggregate French prices. These weights are those used by INSEE, and represent the proportion of value of production due to each commodity, averaged over several years. This aggregate cereals price is then expressed in dollars per quintal (1 quintal = 220.46 lbs.), and can then be converted into francs per quintal using appropriate exchange rate values. As described below, several exchange rate simulations are performed. Exchange rate data come from the International Financial Statistics tables, published by the International Monetary Fund.

For milk, U.S. prices are expressed in dollars per hundred pounds, and French prices in francs per 100 liters. U.S. prices are converted into dollars per 100 liters, using the weight of 8 pounds of milk per gallon and 3.78 liters per gallon.

All price and exchange rate series used in the following simulations can be found in appendix C.

VI.5.2. Impact of cereals prices on cereals production

In this section, the impact on cereals production of three alternative price scenarios is presented. First, French cereals production is estimated using U.S. prices for cereals, everything else remaining the same. This is done under two alternative exchange rate regimes, using (1) the actual exchange rate for each particular year, and (2) the average exchange rate over the period. Second, the impact on cereals production of an overall 10 percent decrease in European support prices is simulated.[90] Table VI.13 shows French cereals production, as predicted by our estimated model, and as it would be under the alternative scenarios considered.

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[89] A bushel of grain weighs 60, 48, 56, and 32 pounds, respectively for wheat, barley corn, and oats.

[90] It is assumed here that decreases in support prices are reflected in similar decreases in market prices. This holds as long as there is excess supply.

Table VI.13. Cereals production under alternative price scenarios

Year	Actual French Prices	United States Prices Actual Exchange Rate	United States Prices Average Exchange Rate	Overall Price Decrease of 10 Percent
1960	6366.8	5403.4	5625.5	5664.6
1961	5823.3	5039.9	5246.9	5177.6
1962	6308.1	5604.6	5806.1	5702.7
1963	6938.1	5719.9	5907.9	6285.7
1964	7062.4	5672.1	5833.0	6357.2
1965	7451.9	6262.2	6422.5	6773.1
1966	7474.7	6474.4	6635.6	6790.9
1967	8995.3	7526.7	7679.3	8281.6
1968	9934.9	8277.2	8400.8	9243.7
1969	11013.7	9542.8	9487.7	10320.6
1970	10023.1	8856.9	8811.7	9372.4
1971	11981.0	10510.2	10548.4	11336.2
1972	13495.4	12394.3	12478.7	12826.9
1973	13832.0	13960.8	14336.4	13220.4
1974	13899.7	13990.3	14516.8	13299.8
1975	12525.0	11742.6	12163.5	11884.8
1977	12454.8	11053.5	11232.9	11872.7
1978	13983.6	12557.4	12941.7	13361.5
1979	14713.4	13422.2	13921.0	14078.2
1980	16179.4	15123.2	15446.9	15557.7
1981	15120.3	14249.1	14136.5	14539.8
1982	16400.3	15513.1	15159.3	15808.1
1983	17657.0	17169.8	16429.0	17079.2
1984	19438.3	18928.8	18039.6	18880.3

The first of these simulations may be the more telling, since it provides a comparison of cereals production under prices received by French and U.S. farmers under actual exchange rate conditions. Since prices appear to have been lower in the U.S. than in France over the period, French production would have been generally lower had U.S. prices prevailed in France. The years 1973 and 1974 are exceptions, since production would have been roughly the same under the two price scenarios in these years due to unusually high prices in the U.S. Using averages of the first three years of the data set and of the last three years, the decreases in cereals production that would have occurred under U.S. prices are estimated to be 13.2 percent in the early years (1960-1962) and 3.5 percent in the later years (1982-1984). Quantity would drop almost as much in the later years, but from a larger production base and, hence, this quantity drop corresponds to a smaller percentage decline.

Some of the differences between French cereals production under actual French and U.S. prices are a reflection of exchange rate variations. These variations are eliminated in the second simulation, for which the average exchange rate over the period was used. The results obtained are reported in the third column of table VI.13. Compared to the first scenario, differences in production under French and U.S. prices are smaller when the actual exchange rate (expressed in francs per dollar) was low, i.e. in the early years, and larger when the exchange rate was high, i.e. in the later years. The estimated decreases in production relative to the French prices situation are 9.8 percent and 7.23 percent, respectively in the earliest (1960-1962) and the latest (1982-1984) years. These percentages correspond to a decrease in quantity that is twice as large in the 1980's as in the early 1960's. As expected, the exchange rate effect is strong in the 1980's, when exchange rate values were much higher than during the rest of the period of study: the estimated decrease in production in the 1980's is more than doubled when the average exchange rate was used than when the actual rate was used. Notice that, while the exchange rate was 9.59 francs per dollar at the end of the period of study (in 1984), it is currently around 6.10, which is relatively close to 5.37, the average over the period of our study. In these exchange rate conditions, cereals production in France may drop by as much as 7 percent were prices to align with unchanged U.S. prices.

The last column of table VI.13 simulates the effect on cereals production of an across-the-board decline of 10 percent in the four French agricultural output prices. In that scenario, production would decrease by 10.6 percent in the early years and by 3.2 percent in the later years. These effects are very similar to those obtained when U.S. prices and actual exchange rates were used.

In summary, cereals prices have been substantially higher in France than in the U.S. over the period of study, regardless of the exchange rate fluctuations. When the exchange rate was very high, in 1983 and 1984, imposing U.S. prices in France would still have resulted in a drop in production of about three percent. However, had exchange rates remained around their average value of the past 30 years, this decline would be doubled. Under these circumstance, if prices became similar to U.S. prices at the end of the period, the production increase from 1960 to 1984 would be almost 9 percent smaller than under French prices.

VI.5.3. Impact of milk prices on milk production

In this section, the same scenarios as above are applied to milk production. The results obtained are quite different because differences in milk prices between France and the U.S. are much smaller for milk than for cereals. Simulation results are presented in table VI.14. Using U.S. prices and actual exchange rate values instead of actual French prices, everything else remaining the same, milk production would have increased in France during the first three years of the study (+ 5.3 percent in 1960-1962), would not have appreciably changed until 1980, and would have sharply increased from 1981 to 1984 (+ 14.6 percent). This increase in the later years can be attributed largely to the stronger value of the dollar. If the average exchange rate is used instead of its actual value, milk production is estimated to be slightly lower with U.S. prices than with French prices in 1982-1984 (− 1.1 percent). However, except for these last two years, using the average exchange rate over the period of study shows that milk production would have increased if French farmers had received U.S. prices rather than French prices.

Consequently, it does not appear that French farmers have received average prices higher than their U.S. counterparts over the period of study, whether exchange rate fluctuations are ignored or not. In fact, according to our computations, milk prices have been on average slightly higher in the U.S. than in France, over the period of study.

The last column of table VI.14 reports the estimated milk production that would be obtained if all French output prices fell by 10 percent. The induced production decrease appears to be relatively small, and proportionately greater in the earlier years than in the later years. In fact, milk production is estimated to decrease only by an average 3.6 percent in 1960-1962, and by 2.1 percent in 1982-1984 in response to this 10 percent price decline. This inelastic response has important policy implications, as is discussed next.

VI.6. Policy implications

Despite finding some results inconsistent with our a priori expectations, especially in the long-run estimation, the overall performance of the model is fairly good, if one considers the large number of coefficients that were estimated. Individual coefficients must be interpreted with caution since some bias is apparent in the results. Nevertheless, these biases are unlikely to alter the major trends identified by the model, and these have several important policy implications.

First and foremost, technological change is found to have played a major role in the growth of agricultural production in France over the period of study. Both for cereals and milk, the two major commodities produced in France, the proportion of growth explained by the technological variables

Table VI.14. Milk production under alternative price scenarios

Year	Actual French Prices	United States Prices Actual Exchange Rate	United States Prices Average Exchange Rate	Overall Price Decrease of 10 Percent
1960	9724.1	10503.0	11057.0	9343.6
1961	9802.0	10282.0	19762.6	9433.4
1962	9918.4	10234.9	10660.0	9588.1
1963	10302.0	10310.0	10735.9	9956.7
1964	10864.1	10692.4	11125.7	10490.0
1965	11388.7	11269.1	11708.4	11018.3
1966	11473.5	12065.0	12506.3	11116.6
1967	12191.5	12794.5	13296.9	11824.5
1968	12649.6	13297.7	13755.1	12278.0
1969	12540.6	14033.3	13821.0	12171.8
1970	12033.3	13575.3	13410.7	11724.8
1971	12550.4	13424.9	13576.1	12223.9
1972	13080.6	13439.2	13697.9	12708.6
1973	12662.3	12807.1	13482.5	12339.2
1974	12315.7	12614.1	13605.7	12036.2
1975	12668.0	12812.2	13776.3	12340.6
1977	12875.4	12985.9	13637.4	12586.6
1978	13056.8	12711.3	13984.9	12755.5
1979	13412.5	12962.4	14493.3	13074.5
1980	14566.8	14609.3	15574.5	14230.3
1981	14405.6	15682.9	15284.2	14081.3
1982	14707.2	16191.9	14927.6	14380.6
1983	15066.5	17336.5	14860.8	14748.6
1984	14618.6	17347.9	14116.6	14311.0

was very high. French public agricultural research has expanded enormously since 1960 and the marginal products of these agricultural research expenditures were estimated to be quite large. Even though these impacts have to be tempered by positive biases affecting the estimated coefficients, the main implication of this result is that French agricultural production, at least for the main commodities, has benefited from important technological gains and is likely to be in a favorable position of competitiveness with respect to most agricultural nations.[91] If France finds herself in a situation of comparative advantage, we should expect to see her approach to trade negotiations shifting toward a freer market stance, in which her comparative advantage would reap the largest benefits. Recent developments both within European Community price setting negotiations and within the context of the new round of multilateral trade negotiations seem to indicate such a policy shift in the French position.

Second, an important part of this rapid technological change has been attributed to the international availability of new technologies, which was measured in this study by the rate of agricultural U.S. productivity. This accounted for a large part of the growth in milk production, causing it to increase by more than 48 percent over the period. Its impact on cereals production was estimated at 22.6 percent. The latter effect may seem like a small figure compared to an overall cereals production growth of 192 percent, but it is a large impact by itself.

The implications of international technology transfers for policy making are far-reaching, especially from the U.S. perspective. Even if the above figures are biased, it seems very likely that the technological effort pursued by the United States over the last few decades has greatly benefited countries like France. In a time of shrinking export markets and fierce export competition, technological edge becomes a vital necessity. It will become so even more if the on-going trade negotiations succeed in liberalizing trade. National investments in agricultural research, however, become a two-edged sword if international technology transfers occur. If the gains to other

[91] In a recent study comparing production costs for cereals in the European Community, Stanton concluded that the wheat farmers of the Paris Basin had production costs rivaling those of North American farmers, using 1982 exchange rates, despite average yields around 100 bushels per acre.

countries were included, the world returns to U.S. research may turn out to be much larger than the national returns. At the same time, the research may not help U.S. agriculture as much as anticipated, especially in the long run. According to these results, the problem of protection of national research is likely to become a part of the trade policy debate.

Third, the relative sizes of the estimated impacts of technological change and price policies raises an important question. Recall that technological change was estimated to induce most of the growth in cereals and milk, while even a 10 percent reduction in prices resulted in output reductions of only 3.2 and 2.1 percent, respectively for cereals and milk productions. If supply curves are inelastic, as they are in our results, and if most of the output growth comes from technology-induced shifts of the supply curve, then international negotiations aimed at price support reductions in order to reduce world excess production (one of the goals of the current Uruguay round) may be less effective than hoped for in reducing surpluses, even if the negociations are succesful.

It can be argued, however, that it is because of the rapid technological change that price setting becomes a critical issue. With cereals production in France about three times higher in 1984 than it was in 1960, largely because of technological change, a price reduction of 10 percent would induce a reduction in quantity supplied three times higher in 1984 than in 1960, if we assume constant supply elasticities over the period. Because technological change has increased production so drastically, the reduction in quantities supplied would be quite large. Such a price decline would also stimulate domestic demand. Even with the inelastic demands that characterize most developed countries, the increase in quantity demanded would probably be fairly large, since again we apply small elasticities to large quantities. With this additional effect of increased domestic demand, price reductions would considerably reduce domestic excess supply relative to the world market in the short run. Over time, our results suggest that any gains could be eroded fairly rapidly if any price rigidities remain and technological change continues to occur. If so, the support agriculture receives as the result of national public research expenditures could become an important part of trade negotiations.

CHAPTER SEVEN

SUMMARY AND CONCLUSIONS

This chapter is divided into three sections. In the first section, the dissertation is summarized by bringing out key points from each chapter. The results of the model have important policy implications which are summarized in the second section. In the last section, some suggestions for further research are offered.

VII.1. Summary of the dissertation

The goal of this study has been to analyze the sources of growth in French agriculture. Agricultural production in France has increased considerably since the late fifties (for example, cereal production increased by almost 200 percent between 1960 and 1984). Within the European Community (EC), France accounts for about 27 percent of the total agricultural production, this percentage being generally higher for the main products exported by the EC (for example, more than 37 percent of the EC wheat is produced in France).

Over time, the EC, led by France, has become a net exporter on world markets (especially of cereals and milk). This has generated a heated policy debate between France and the U.S. The debate centers around different views of the sources of growth in French agricultural production. U.S. policy-makers, in general, attribute growth to the high prices provided by the Common Agricultural Policy (CAP), and charge the French with unfair competition. On the French side, the argument is that growth has been created by a complex modernization process, involving technical change, structural change and substitution of capital for labor. The French belief is that most of the growth would have occurred irrespective of the level of price supports.

Our goal in this study has been to provide some empirical estimates concerning which effects, out of these conflicting views, have been dominant. The major hypothesis tested in this study is that the increase of agricultural production in France between 1960 and 1984 has been due more to the combined effect of research, education, and other sources of structural change in agriculture, than to price and marketing policies, with their domestic and foreign trade aspects. Corollary hypotheses were also tested, and can be explicitly found in chapter I.

Chapter II summarizes the French economic situation, tracing the performance of the economy since the fifties, and then concentrating on the evolution of the agricultural sector and the agricultural policies of this period. It describes a vigorously growing economy, up to the first oil shock of 1973-1974, and then slower growth. Interactions between the agricultural sector and the rest of the economy take place for the most part through the labor and capital markets. Over the period of study, agricultural growth occurs in the context of a rapid labor migration towards the non-agricultural sectors and a rapid capitalization within agriculture. This rapid capitalization was favored by dynamic technical change due at least in part to a tremendous increase in public research expenditures. Rapid growth in agriculture has also been favored by European price policies introduced through the Common Agricultural Policy of the EC. These price support policies have used by far the largest part of the Community's budget, because of their open-ended nature -- artificially high prices are provided for many commodities without any production constraints. Structural policy has been left mostly to the individual member states. French credit and structural policies have been designed to help shape the sector and have complemented EC price policies. Determining the relative impacts on agricultural growth of all of these forces has been the main goal of this study.

Many concerns pertinent to our goal have been raised in the literature. The most relevant for the French case are reviewed in chapter III. The model developed in this study allows us to address many of the key issues. Among these are: (1) the effects of price policies on output, variable input use and capital and family labor use in French agriculture; (2) the effects of French structural change and credit policies on both the level of resource utilization in agriculture and the level of agricultural output; (3) the role of technological change in the growth of French agricultural production over time; (4) the relative importance of French public agricultural research and international technology transfers in overall technological growth in French agriculture; (5) the presence of adjustment costs in the labor and capital markets, causing these markets to be in disequilibrium in the short run; and (6) the impacts of these disequilibria on output growth, that involve comparisons between the short and the long run. Other concerns raised in chapter III are beyond the scope of our study. These include (1) endogenizing research demand and supply, (2) separating the effects of high prices and of stable prices on output growth, and (3) endogenizing the other sectors of the economy.

Models incorporating adjustment lags for some inputs -- the quasi-fixed inputs -- have been developed along two alternative approaches, as discussed in chapter IV. The first approach is based on dynamic economic optimization, incorporating costs of adjustment for quasi-fixed factors. These models provide optimal adjustment paths for the quasi-fixed factors. However, empirical applications require the use of various restrictive assumptions. In particular, this approach is usually applied to univariate analysis of production. Also, price expectations are usually assumed to be static. Adjustment costs may be either external or internal. The ad hoc specification of external adjustment costs makes it a somewhat unattractive approach, and short-run disequilibrium may be due to factors outside the sector, which is contrary to the assumption of internal adjustment costs. This dilemma reduces the attractiveness of currently available dynamic specifications, and raises the possibility of using an approach that builds on the quasi-fixed input concept to provide information on the short and long run, without depending on the adjustment cost assumption.

The second approach discussed in chapter IV is the long-run variable profit function approach. This approach does not require any assumption about the causes of short-run disequilibrium. It generates short- and long-run output supply and variable-input demand functions, as well as optimal levels of the quasi-fixed inputs, given other exogenous factors (prices, technology, and other fixed factors). However, it does not provide any information on the adjustment paths of the quasi-fixed factors between the short and the long run. The main advantage of this approach is its compatibility to multivariate analysis. Since adjustment paths are not the focus of our study, this approach is followed to develop the model used in this study.

The model itself is presented in chapter V. It is a sectoral model of the French agricultural sector, and includes the elements mentioned earlier, i.e. technical change, structural change, price policies, and transfers of labor and capital between agriculture and the rest of the economy. Price policies are assumed exogenous, depending upon a European policy process that responds little to the performance of the French agricultural sector. Technical and structural change are also assumed exogenous in the model. On the other hand, all the variables that are controlled by the decision-maker are endogenized. This includes not only output supplies and use of variable inputs, but, in the long run, determination also of the optimal quantities of the quasi-fixed factors, family labor and capital. The model is based on the assumption of profit maximization, and uses results of duality theory to derive short- and long-run output supply and input demand equations. Agricultural output is disaggregated into supply equations for cereals, other crop products, milk, and other animal products. Input equations represent the demands by the agricultural sector for feeds, fertilizer-energy, and hired labor. The data used in estimation is discussed at the end of chapter V. Three series (French agricultural research expenditures, preferential credit rates, agricultural labor) were collected from unpublished sources specifically for the study.

Results of estimation are presented in chapter VI. By and large, short-run results conform to theoretical expectations. Own-price elasticities are compatible with upward-sloping output supply curves and downward-sloping input demand curves, in general, and short-run curves are inelastic.

Most cross-price elasticities have the expected signs, as do the impacts of most of the quasi-fixed variables and the variables used to capture technological change and credit and structural policies. These results are used to test the hypotheses developed in the first chapter. For both cereals and milk, technological change appears to have played the major role in inducing production growth. If no other forces had been present, technological change would have caused a production increase of 435.4 and 71.0 percent, respectively for cereals and milk. These increases, offset to some extent by falling real output prices and migration of labor out of agriculture, correspond to 217.9 and 137.5 percent of the increases in these products from 1960-1962 to 1982-1984. The increase is attributed mostly to French research expenditures in the case of cereals. For milk production, however, the production increase due to technological change is attributed to both French research expenditures, for 31.3 percent, and to transfers of technology, for 68.7 percent. Credit policies have also played a role in the growth of output production. Although their role is modest compared to the impact of technological change, credit policies are responsible for 8.6 and 10.4 percent of the growth in cereals and milk production.

The long-run results of the model must be evaluated with caution because of the arbitrary process that was followed to estimate the remaining terms of the profit function. Nevertheless, some key differences appear between those results obtained with long-run assumptions (quasi-fixed factors adjust to their optimal values) and those obtained with short-run conditions (quasi-fixed factors take on their actual values). First, output supply curves appear more elastic in the long run than in the short run which conforms to theory. However, own-price supply elasticities remain substantially smaller than one.

Second, it was expected that the full impact of technological change on output would be felt only in the long run, when family labor and capital stock adjust to their equilibrium values. The results obtained did not conform entirely to this expectation. As discussed in chapter VI, this is explained by a wrong sign on the estimated coefficient of the interaction term between *USP* and family labor, and by a correct sign but biased values on the terms involving French agricultural public expenditures. It is likely that the large number of variables that had to be dropped to estimate the long-run model introduced some bias, which is reflected in at least these three coefficients.

Lastly, capital in agriculture is estimated to have been below optimal over the entire period of study. In contrast, our model suggests that there was excess labor in agriculture in the beginning of the period of study, but that labor was below optimal at the end of the period. These results do not rule out the possibility that, were price supports removed, there may be excess capital and excess labor in the agricultural sector.

To determine the impact of price policies on agricultural output growth, the impacts of alternative price scenarios on cereals and milk production are estimated. Cereals prices have been substantially higher in France than in the U.S. over the period of study, regardless of exchange rate fluctuations. When the exchange rate was high, in 1983 and 1984, imposing U.S. prices in France would still have resulted in a drop in production of about 3 percent. Had exchange rates remained around their average value of the past 30 years, this decline would be doubled. Under these circumstances, if prices became similar to U.S. prices at the end of the period, the production increase from 1960 to 1984 would be almost 9 percent smaller than under French prices.

By contrast, it does not appear that French farmers have received average milk prices higher than their U.S. counterparts, whether exchange rate fluctuations are ignored or not. In fact, according to our computations, milk prices have been on average slightly higher in the U.S. than in France, over the period of study. In another simulation, the effect on cereals and milk production of an across-the-board decrease of 10 percent in all output prices is estimated. The induced production decreases were small, reflecting the inelastic nature of the supply curves.

VII.2. Policy implications

The results of the model have several important policy implications. They are discussed in chapter VI, and summarized here.

First, French agricultural production is found to have benefited from important technological gains since the early 1960's. This may have brought France into a situation of comparative advantage with respect to agriculture compared to most other nations. If such is the case, we should expect to see French policy-makers shift toward a freer market stance in trade negotiations.

Second, an important part of the rapid technological change in milk production has been attributed to the international availability of new technologies, which was measured in this study by the level of U.S. agricultural productivity. Thus, it seems very likely that the technological effort pursued by the United States over the last few decades has greatly benefited countries like France, even though most technologies probably required some adaptation to local conditions. This raises the necessity of taking technology transfers into account when evaluating the returns to research in the U.S.. Furthermore, in a time of shrinking export markets, the problem of protection of national research is likely to become a part of trade policy debates.

Third, the small role of price policies relative to technological change in explaining agricultural growth raises questions about the consequences of trade negotiations aimed at reducing support prices. It is because of the rapid technological change that price setting has become such a critical issue. With cereals production in France about three times higher in 1984 that it was in 1960, a price reduction of 10 percent in both cases would induce a reduction in quantity supplied three times higher in 1984 than in 1960, assuming constant supply elasticities. This, added to the concomitant increase in domestic demand, would considerably reduce domestic excess supply relative to the world markets. Thus a step toward eliminating world excess production, one of the major goals of trade negotiations, would be achieved. However, our results suggest that such steps would be quickly outweighed by continual outward supply shifts if efforts to develop agricultural technology are pursued.

VII.3 Suggestions for further research

From the discussion above, the results of this study could be built upon in at least four ways.

First, the results obtained in this study were heavily influenced by data limitations. Many data series are not published in France, and efforts in that direction are necessary if one is to more accurately understand the structure and the evolution of French agricultural production. In particular, there is a dearth of data concerning expenditures on research and extension, despite the importance of these factors in the growth process. A data series on French research expenditures was developed for the needs of this study, and will be improved in connection with current work by the International Service for National Agricultural Research (ISNAR). No such series concerning extension expenditures is presently available.

Another data limitation is the limited time period for which reliable data is available, contraining this study to start in 1960. This led to econometric difficulties, because of the small number of degrees of freedom available. It would therefore be interesting to conduct a similar study combining cross-sections and time-series data, and thus to compare different regions of production in France.

Third, separating the effects of high prices and of stable prices on output growth is one of the issues raised in chapter III. Since price stability has consequences on farmers' revenue and farmers' investment decisions, it is likely to accelerate the adoption of technical change. Incorporating price stability in the model would thus reduce the biases on the coefficients of the technological change variables. However, it requires consideration of farmers' risk preferences as well as the sources of income variability in agriculture, created both by supply instability and demand instability.

Fourth, an issue raised in chapter III concerns the importance of endogenizing research expenditures when analyzing agricultural growth. On the demand side, this requires taking into account the potential impact of changes in product demand and changes in relative factor prices on the demand for technological change by the agricultural sector. The level of research funding depends on supply factors as well, such as the availability of funds in the economy, itself dependent on the growth of the economy, the tax structure, the political will to prioritize agriculture relative to other sectors and so on. Incorporating these issues would necessitate expanding the scope of the study: possibly, a general equilibrium framework for the entire French economy would be needed to capture the interactions involved. The policy implications of such a study could be far-reaching, and would justify the investment of resources necessary to its completion.

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APPENDIX A

THE USE OF TAYLOR'S EXPANSIONS

This appendix is organized as follows. The general form of a Taylor's expansion about a specific point is presented first. It is applied to develop first- and second-order expansions for the two variable case $y = f(x_1, x_2)$. The results obtained show how to interpret the main functional forms used in empirical works as Taylor's expansions.

General form of a Taylor's expansion

The unknown $y = f(x)$ can be approximated about the point a by a Taylor's expansion of degree n:

$$f(x) = f(a) + f'(a)\frac{(x-a)}{1!} + f''(a)\frac{(x-a)^2}{2!} + \ldots + f^{(n)}(a)\frac{(x-a)^n}{n!}$$

where $f^{(i)}$ represents the ith-degree derivative of f with respect to x, and $k!$ stand for the product: $k(k-1)(k-2)\ldots1$.

In what follows, a two variable function $y = f(x_1, x_2)$ is approximated by first- and second-order Taylor's expansion.

First-order Taylor's expansion

The unknown function $y = f(x_1, x_2)$ is approximated about the point (a, b) by a Taylor's expansion of degree one. Using the notation: $f = f(a, b)$, $f_1 = \dfrac{\partial f(a,b)}{\partial x_1}$, and $f_2 = \dfrac{\partial f(a,b)}{\partial x_2}$, this yields:

$$y = f(x) = f + f_1(x_1 - a) + f_2(x_2 - b)$$
$$= (f - f_1 a - f_2 b) + f_1 x_1 + f_2 x_2$$

This can be written:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2$$

If logarithms are used instead of levels, we obtain:

$$\log y = \beta_0 + \beta_1 \log x_1 + \beta_2 \log x_2 \text{ or, equivalently } y = \beta_0 x_1^{\beta_1} x_2^{\beta_2}$$

Thus, the Cobb-Douglas is a first-order Taylor's expansion of $\log y$ in powers of $\log x_i$.

Second-order Taylor's expansion

The previous notation is extended to the second-degree derivatives:

$$f_{11} = \frac{\partial f^2(a,b)}{\partial x_1^2},\ f_{12} = \frac{\partial f^2(a,b)}{\partial x_1 \partial x_2},\ f_{21} = \frac{\partial f^2(a,b)}{\partial x_2\, \partial x_1} \text{ and } f_{22} = \frac{\partial f^2(a,b)}{\partial x_2^2}$$

The second-order Taylor's expansion of the function $y = f(x_1, x_2)$ about the point (a,b) is:

$$f(x_1, x_2) = f + f_1 (x_1 - a) + f_2 (x_2 - b)$$
$$+ \frac{f_{11}}{2}(x_1 - a)^2 + \frac{f_{12}}{2}(x_1 - a)(x_2 - b)$$
$$+ \frac{f_{21}}{2}(x_2 - b)(x_1 - a) + \frac{f_{22}}{2}(x_2 - b)^2$$

This yields:

$$
\begin{aligned}
f(x_1, x_2) &= f + f_1 x_1 - f_1 a + f_2 x_2 - f_2 b + \frac{f_{11}}{2} x_1^2 + \frac{f_{11}}{2} a^2 - f_{11} x_1 a \\
&+ \frac{f_{12}}{2} x_1 x_2 - \frac{f_{12}}{2} x_1 b - \frac{f_{12}}{2} a x_2 + \frac{f_{12}}{2} ab + \frac{f_{21}}{2} x_2 x_1 \\
&- \frac{f_{21}}{2} x_2 a - \frac{f_{21}}{2} b x_1 + \frac{f_{21}}{2} ab + \frac{f_{22}}{2} x_2^2 + \frac{f_{22}}{2} b^2 - f_{22} x_2 b \\
&= [f - f_1 a - f_2 b + \frac{f_{11}}{2} a^2 + \frac{f_{12}}{2} ab + \frac{f_{21}}{2} ab + \frac{f_{22}}{2} b^2] \\
&+ [f_1 - f_{11} a - \frac{f_{12}}{2} b - \frac{f_{21}}{2} b] \, x_1 + [f_2 - \frac{f_{12}}{2} a - \frac{f_{21}}{2} a - f_{22} b] \, x_2 \\
&+ \frac{f_{11}}{2} x_1^2 + \frac{f_{22}}{2} x_2^2 + [\frac{f_{12}}{2} + \frac{f_{21}}{2}] \, x_1 x_2
\end{aligned}
$$

The above result can be written:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1^2 + \beta_4 x_2^2 + \beta_5 x_1 x_2$$

It is then easy to show that the Translog is a second-order Taylor's expansion of $\log y$ in powers of $\log x_i$, and that the Generalized Leontieff and Quadratic are second-order expansions of y in powers of $\sqrt{x_i}$ and x_i , respectively. These functional forms are as follows:

$$\text{Translog} : y = \beta_0 + \sum_i \beta_i \log x_i + \sum_i \sum_j \gamma_{ij} (\log x_i)(\log x_j)$$

$$\text{Generalized Leontieff} : y = \beta_0 + \sum_i \beta_i x_i^{1/2} + \sum_i \sum_j \gamma_{ij} \, x_i^{1/2} x_j^{1/2}$$

$$\text{Quadratic} : y = \beta_0 + \sum_i \beta_i x_i + \sum_i \sum_j \gamma_{ij} \, x_i x_j$$

APPENDIX B

THE EMPIRICAL PROFIT FUNCTION

In this appendix, the long-run variable profit function -- from which the entire model is derived -- is presented. Then, the derivation of the profit function is taken with respect to cereals price, which yields the short-run supply function for cereals. This is an example of the procedure followed to obtain the short-run output supply and variable input functions. The derivative of the profit function with respect to fixed capital is also computed, and typifies the derivation necessary to obtain optimal long-run values.

The variables used below are as defined in table V.1. The b_i's represent coefficients to be estimated. As explained in chapters V and VI, some variables are actually lagged (e.g. output prices and research expenditures).

The profit function

$$
\begin{aligned}
\Pi = {} & b_0 + b_C P_C + b_V P_V + b_M P_M + b_N P_N + b_F r_F + b_H r_H + b_D r_D \\
& + b_K K_A^F + b_L L_A^F + b_T CL + b_A PL + b_E WEA + b_R RES + b_U USP \\
& + b_X CR + b_B REM + b_S SAF + b_I IVD + b_G DUM \\
& + \frac{1}{2} b_{CC} P_C^2 + \frac{1}{2} b_{VV} P_V^2 + \frac{1}{2} b_{MM} P_M^2 + \frac{1}{2} b_{NN} P_N^2 + \frac{1}{2} b_{FF} r_F^2 + \frac{1}{2} b_{HH} r_H^2 + \frac{1}{2} b_{DD} r_D^2 \\
& + \frac{1}{2} b_{KK} (K_A^F)^2 + \frac{1}{2} b_{LL} (L_A^F)^2 + \frac{1}{2} b_{TT} CL^2 + \frac{1}{2} b_{AA} PL^2 + \frac{1}{2} b_{EE} WEA^2 + \frac{1}{2} b_{RR} RES^2 \\
& + \frac{1}{2} b_{UU} USP^2 + \frac{1}{2} b_{XX} CR^2 + \frac{1}{2} b_{BB} REM^2 + \frac{1}{2} b_{SS} SAF^2 + \frac{1}{2} b_{II} IVD^2 + \frac{1}{2} b_{GG} DUM^2 \\
& + b_{CV} P_C P_V + b_{CM} P_C P_M + b_{CN} P_C P_N + b_{CF} P_C r_F + b_{CH} P_C r_H \\
& + b_{CD} P_C r_D + b_{VM} P_V P_M + b_{VN} P_V P_N + b_{VF} P_V r_F + b_{VH} P_V r_H + b_{VD} P_V r_D \\
& + b_{MN} P_M P_N + b_{MF} P_M r_F + b_{MH} P_M r_H + b_{MD} P_M r_D + b_{NF} P_N r_F + b_{NH} P_N r_H \\
& + b_{ND} P_N r_D + b_{FH} r_F r_H + b_{FD} r_F r_D + b_{HD} r_H r_D
\end{aligned}
$$

(*continued*)

$$
\begin{aligned}
&+ b_{CK} P_C K_A^F + b_{CL} P_C L_A^F + b_{CT} P_C CL + b_{CA} P_C PL + b_{CE} P_C WEA + b_{CR} P_C RES \\
&+ b_{CU} P_C USP + b_{CX} P_C CR + b_{CB} P_C REM + b_{CS} P_C SAF + b_{CI} P_C IVD + b_{CG} P_C DUM \\
&+ b_{VK} P_V K_A^F + b_{VL} P_V L_A^F + b_{VT} P_V CL + b_{VA} P_V PL + b_{VE} P_V WEA + b_{VR} P_V RES \\
&+ b_{VU} P_V USP + b_{VX} P_V CR + b_{VB} P_V REM + b_{VS} P_V SAF + b_{VI} P_V IVD + b_{VG} P_V DUM \\
&+ b_{MK} P_M K_A^F + b_{ML} P_M L_A^F + b_{MT} P_M CL + b_{MA} P_M PL + b_{ME} P_M WEA + b_{MR} P_M RES \\
&+ b_{MU} P_M USP + b_{MX} P_M CR + b_{MB} P_M REM + b_{MS} P_M SAF + b_{MI} P_M IVD \\
&+ b_{MG} P_M DUM + b_{NK} P_N K_A^F + b_{NL} P_N L_A^F + b_{NT} P_N CL + b_{NA} P_N PL + b_{NE} P_N WEA \\
&+ b_{NR} P_N RES + b_{NU} P_N USP + b_{NX} P_N CR + b_{NB} P_N REM + b_{NS} P_N SAF + b_{NI} P_N IVD \\
&+ b_{NG} P_N DUM + b_{FK} r_F K_A^F + b_{FL} r_F L_A^F + b_{FT} r_F CL + b_{FA} r_F PL + b_{FE} r_F WEA \\
&+ b_{FR} r_F RES + b_{FU} r_F USP + b_{FX} r_F CR + b_{FB} r_F REM + b_{FS} r_F SAF + b_{FI} r_F IVD \\
&+ b_{FG} r_F DUM + b_{HK} r_H K_A^F + b_{HL} r_H L_A^F + b_{HT} r_H CL + b_{HA} r_H PL + b_{HE} r_H WEA \\
&+ b_{HR} r_H RES + b_{HU} r_H USP + b_{HX} r_H CR + b_{HB} r_H REM + b_{HS} r_H SAF + b_{HI} r_H IVD \\
&+ b_{HG} r_H DUM + b_{DK} r_D K_A^F + b_{DL} r_D L_A^F + b_{DT} r_D CL + b_{DA} r_D PL + b_{DE} r_D WEA \\
&+ b_{DR} r_D RES + b_{DU} r_D USP + b_{DX} r_D CR + b_{DB} r_D REM + b_{DS} r_D SAF + b_{DI} r_D IVD \qquad (B.1) \\
&+ b_{DG} r_D DUM + b_{KL} K_A^F L_A^F + b_{KT} K_A^F CL + b_{KA} K_A^F PL + b_{KE} K_A^F WEA + b_{KR} K_A^F RES \\
&+ b_{KU} K_A^F USP + b_{KX} K_A^F CR + b_{KB} K_A^F REM + b_{KS} K_A^F SAF + b_{KI} K_A^F IVD + b_{KG} K_A^F DUM \\
&+ b_{LT} L_A^F CL + b_{LA} L_A^F PL + b_{LE} L_A^F WEA + b_{LR} L_A^F RES \\
&+ b_{LU} L_A^F USP + b_{LX} L_A^F CR + b_{LB} L_A^F REM + b_{LS} L_A^F SAF + b_{LI} L_A^F IVD + b_{LG} L_A^F DUM \\
&+ b_{TA} CL\, PL + b_{TE} CL\, WEA + b_{TR} CL\, RES + b_{TU} CL\, USP \\
&+ b_{TX} CL\, CR + b_{TB} CL\, REM + b_{TS} CL\, SAF + b_{TI} CL\, IVD + b_{TG} CL\, DUM + b_{AE} PL\, WEA \\
&+ b_{AR} PL\, RES + b_{AU} PL\, USP + b_{AX} PL\, CR + b_{AB} PL\, REM + b_{AS} PL\, SAF + b_{AI} PL\, IVD \\
&+ b_{AG} PL\, DUM + b_{ER} WEA\, RES + b_{EU} WEA\, USP + b_{EX} WEA\, CR + b_{EB} WEA\, REM \\
&+ b_{ES} WEA\, SAF + b_{EI} WEA\, IVD + b_{EG} WEA\, DUM + b_{RU} RES\, USP + b_{RX} RES\, CR \\
&+ b_{RB} RES\, REM + b_{RS} RES\, SAF + b_{RI} RES\, IVD + b_{RG} RES\, DUM + b_{UX} USP\, CR \\
&+ b_{UB} USP\, REM + b_{US} USP\, SAF + b_{UI} USP\, IVD + b_{UG} USP\, DUM + b_{XB} CR\, REM \\
&+ b_{XS} CR\, SAF + b_{XI} CR\, IVD + b_{XG} CR\, DUM + b_{BS} REM\, SAF + b_{BI} REM\, IVD \\
&+ b_{BG} REM\, DUM + b_{SI} SAF\, IVD + b_{SG} SAF\, DUM + b_{IG} IVD\, DUM
\end{aligned}
$$

Short-run cereals output equation

The first derivatives of the profit function with respect to output and variable input prices are respectively the output supply and the negative of the input demand equations. For example:

$$Q_C = \frac{\partial \Pi}{\partial P_C} = b_C + b_{CC} P_C + b_{CV} P_V + b_{CM} P_M + b_{CN} P_N + b_{CF} r_F + b_{CH} r_H + b_{CD} r_D$$
$$+ b_{CK} K_A^F + b_{CL} L_A^F + b_{CT} CL + b_{CA} PL + b_{CE} WEA + b_{CR} RES \qquad (B.2)$$
$$+ b_{CU} USP + b_{CX} CR + b_{CB} REM + b_{CS} SAF + b_{CI} IVD + b_{CG} DUM$$

Derivation of the long-run model

This section presents the successively computed long-run equilibrium values of the quasi-fixed factors, K_A^{F*} and L_A^{F*}, and the long-run output supply and input demand equations (although only one representative equation is given).

To simplify the notation, ζ is the set of variables *CL*, *PL*, *WEA* , *RES* , *USP*, *CR*, *REM*, *SAF*, *IVD* and *DUM*, and a generic element of that set is represented by *W*. Similarly, ρ is the set of all the prices P_C, P_V, P_M, P_N, r_F, r_H, and r_D, and a generic element of that set is represented by *P*.

Optimal values of the quasi-fixed factors

The long-run optimal values of the quasi-fixed factors, K_A^{F*} and L_A^{F*}, are obtained by solving the system of equations:

$$r_K = \frac{\partial \Pi}{\partial K_A^F} \quad \text{and} \quad r_L = \frac{\partial \Pi}{\partial L_A^F} \qquad (B.3)$$

where r_K and r_L are the opportunity costs of capital and labor, respectively.

Using the above formulation of the profit function, and the notation just introduced, these two equations are:

$$r_K = b_K + b_{KK} K_A^{F^*} + b_{KL} L_A^{F^*} + \sum_\rho b_{PK} P + \sum_\zeta b_{KW} W$$
$$r_L = b_L + b_{LL} L_A^{F^*} + b_{KL} K_A^{F^*} + \sum_\rho b_{PL} P + \sum_\zeta b_{LW} W$$

This can be written:

$$\begin{aligned} b_{KK} K_A^{F^*} + b_{KL} L_A^{F^*} &= r_K - b_K - \sum_\rho b_{PK} P - \sum_\zeta b_{KW} W \\ b_{KL} K_A^{F^*} + b_{LL} L_A^{F^*} &= r_L - b_L - \sum_\rho b_{PL} P - \sum_\zeta b_{LW} W \end{aligned} \tag{B.4}$$

Because the two equations are linear, they can be solved readily for $K_A^{F^*}$ and $L_A^{F^*}$ This is an advantage of using the quadratic functional form for the normalized profit function. Other flexible functional forms such as the translog or the generalized Leontieff would not yield linear equations, and values of $K_A^{F^*}$ and $L_A^{F^*}$ could not be derived analytically. Here, the optimal values of the quasi-fixed factors are given by:

$$\begin{vmatrix} K_A^{F^*} \\ L_A^{F^*} \end{vmatrix} = \begin{vmatrix} b_{KK} & b_{KL} \\ b_{KL} & b_{LL} \end{vmatrix}^{-1} \begin{vmatrix} r_K - b_K - \sum_\rho b_{PK} P - \sum_\zeta b_{KW} W \\ r_L - b_L - \sum_\rho b_{PL} P - \sum_\zeta b_{LW} W \end{vmatrix}$$

The inverse of the above matrix is:

$$\begin{aligned} \begin{vmatrix} b_{KK} & b_{KL} \\ b_{KL} & b_{LL} \end{vmatrix}^{-1} &= \frac{1}{b_{KK} b_{LL} - (b_{KL})^2} \begin{vmatrix} b_{LL} & -b_{KL} \\ -b_{KL} & b_{KK} \end{vmatrix} \\ &= \begin{vmatrix} a_{KK} & a_{KL} \\ a_{LK} & a_{LL} \end{vmatrix} \end{aligned}$$

Thus, the optimal values of the quasi-fixed factors are given by:

$$\begin{aligned} K_A^{F^*} &= a_{KK} [r_K - b_K - \sum_\rho b_{PK} P - \sum_\zeta b_{KW} W] \\ &\quad + a_{KL} [r_L - b_L - \sum_\rho b_{PL} P - \sum_\zeta b_{LW} W] \end{aligned} \tag{B.5}$$

$$L_A^{F^*} = a_{LK}[r_K - b_K - \sum_\rho b_{PK} P - \sum_\zeta b_{KW} W] + a_{LL}[r_L - b_L - \sum_\rho b_{PL} P - \sum_\zeta b_{LW} W] \quad (B.6)$$

Let us now define the following quantities that will be useful later. For any P :

$$\frac{\partial K_A^{F^*}}{\partial P} = - a_{KK} b_{PK} - a_{KL} b_{PL} = \Delta_{KP}$$
$$\frac{\partial L_A^{F^*}}{\partial P} = - a_{LK} b_{PK} - a_{LL} b_{PL} = \Delta_{LP} \quad (B.7)$$

For any W :

$$\frac{\partial K_A^{F^*}}{\partial W} = - a_{KK} b_{KW} - a_{KL} b_{LW} = \Delta_{KW}$$
$$\frac{\partial L_A^{F^*}}{\partial W} = - a_{LK} b_{KW} - a_{LL} b_{LW} = \Delta_{LW} \quad (B.8)$$

Long-run cereal supply function

As was done for the short-run model, the cereal equation is given as an example of a long-run output supply (or variable input demand) function. To obtain these equations, K_A^F and L_A^F are substituted by their optimal values in the short-run function. This yields:

$$\begin{aligned} Q_C^* = {} & b_C + \sum_\rho b_{CP} P + \sum_\zeta b_{CW} W \\ & + b_{CK} a_{KK} (r_K - b_K - \sum_\rho b_{PK} P - \sum_\zeta b_{KW} W) \\ & + b_{CK} a_{KL} (r_L - b_L - \sum_\rho b_{PL} P - \sum_\zeta b_{LW} W) \\ & + b_{CL} a_{LK} (r_K - b_K - \sum_\rho b_{PK} P - \sum_\zeta b_{KW} W) \\ & + b_{CL} a_{LL} (r_L - b_L - \sum_\rho b_{PL} P - \sum_\zeta b_{LW} W) \end{aligned}$$

By regrouping terms, this becomes:

$$
\begin{aligned}
Q_C^{\blacksquare} = {} & b_C + b_K(-a_{KK}b_{CK} - a_{LK}b_{CL}) + b_L(-a_{KL}b_{CK} - a_{LL}b_{CL}) \\
& - r_K(-a_{KK}b_{CK} - a_{LK}b_{CL}) - r_L(-a_{KL}b_{CK} - a_{LL}b_{CL}) \\
& + \sum_{\rho} P[b_{CP} + b_{CK}(-a_{KK}b_{PK} - a_{KL}b_{PL}) + b_{CL}(-a_{LK}b_{PK} - a_{LL}b_{PL})] \\
& + \sum_{\zeta} W[b_{CW} + b_{CK}(-a_{KK}b_{KW} - a_{KL}b_{LW}) + b_{CL}(-a_{LK}b_{KW} - a_{LL}b_{CW})]
\end{aligned}
$$

Using the notations defined above, this can be written:

$$
\begin{aligned}
Q_C^{\blacksquare} = {} & b_C + b_K\Delta_{KC} + b_L\Delta_{LC} - r_K\Delta_{KC} - r_L\Delta_{LC} \\
& + \sum_{\rho}(b_{CP} + b_{CK}\Delta_{KP} + b_{CL}\Delta_{LP})P \\
& + \sum_{\zeta}(b_{CW} + b_{CK}\Delta_{KW} + b_{CL}\Delta_{LW})W
\end{aligned}
\qquad (B.9)
$$

APPENDIX C

DATA USED IN THE MODEL

Table C.1. Output quantities

Year	Q_C	Q_V	Q_M	Q_N
1960	6114.8	26171.2	9320.3	31482.8
1961	5080.0	23536.4	9735.6	32898.3
1962	6484.8	25789.0	9830.8	33863.5
1963	6170.3	26734.3	10293.3	34055.5
1964	7051.7	27799.1	10471.8	33988.2
1965	7906.0	28754.4	11175.6	35459.4
1966	6889.3	27169.0	11578.2	36844.3
1967	9051.5	30080.7	12109.1	38790.3
1968	9781.4	31782.4	12562.6	39890.9
1969	9994.6	28577.5	12325.3	38761.5
1970	9818.0	32037.0	12142.0	39430.0
1971	11943.7	33538.3	12349.7	40823.7
1972	12887.3	31513.3	13116.8	41122.3
1973	13490.7	31641.8	12037.4	37863.5
1974	12936.2	32824.2	12066.7	40397.6
1975	11948.5	31066.5	12075.3	40622.8
1976	10195.3	27640.6	12144.1	41566.4
1977	11500.0	29070.0	12580.8	41143.5
1978	13643.5	32134.1	12817.4	42414.7
1979	14139.3	33126.5	13327.7	45079.4
1980	15586.5	35240.9	14043.1	46331.3
1981	14885.8	34720.8	14094.0	47110.6
1982	15973.5	36796.0	14382.8	47493.1
1983	16059.1	35875.5	14615.3	47484.5
1984	19696.9	38609.5	14539.5	48646.4

Table C.2. Output prices

Year	P_C	P_V	P_M	P_N
1960	0.775	0.625	0.743	0.685
1961	0.800	0.645	0.730	0.702
1962	0.891	0.763	0.774	0.732
1963	0.875	0.700	0.832	0.855
1964	0.831	0.702	0.850	0.848
1965	0.851	0.733	0.843	0.873
1966	0.912	0.769	0.870	0.912
1967	0.951	0.793	0.898	0.884
1968	0.938	0.795	0.894	0.890
1969	0.925	0.935	0.910	0.977
1970	1.000	1.000	1.000	1.000
1971	1.030	0.992	1.121	1.055
1972	1.091	1.204	1.242	1.196
1973	1.127	1.393	1.282	1.346
1974	1.364	1.456	1.379	1.314
1975	1.398	1.548	1.541	1.457
1976	1.603	1.917	1.679	1.575
1977	1.658	2.058	1.789	1.721
1978	1.759	2.036	1.972	1.809
1979	1.874	2.253	2.130	1.879
1980	2.000	2.349	2.298	1.985
1981	2.259	2.607	2.542	2.230
1982	2.526	2.926	2.858	2.517
1983	2.741	3.294	3.104	2.664
1984	2.537	3.383	3.255	2.775

Table C.3. Variable and quasi-fixed input quantities

Year	K_D	K_F	K_H	K_A^F	L_A^F
1960	2661	2891	839.0	38224	3084.0
1961	2712	3178	802.0	39110	3011.0
1962	3419	3494	764.0	40803	2937.0
1963	3520	3732	727.0	41986	2863.0
1964	3993	4179	693.0	43616	2789.0
1965	4797	4013	660.0	45468	2716.0
1966	5486	4153	629.0	47428	2642.0
1967	5973	4491	599.0	49719	2568.0
1968	5733	5297	584.0	51895	2464.0
1969	5871	5060	508.0	53845	2320.0
1970	6835	5295	439.0	56208	2100.0
1971	7594	5783	399.0	58011	2031.0
1972	8701	5924	376.0	59392	1954.0
1973	9742	6746	371.0	61514	1843.0
1974	9844	6532	378.0	63694	1770.0
1975	9767	5700	375.0	66082	1651.0
1976	10794	6404	352.0	67138	1620.0
1977	10888	6463	324.0	68248	1574.0
1978	11536	6853	301.0	68910	1540.0
1979	12073	7297	293.0	69914	1504.0
1980	12648	7084	286.0	70799	1478.0
1981	12859	6868	275.0	71294	1441.0
1982	13065	6607	261.0	71646	1390.0
1983	12903	6810	251.0	72374	1349.0
1984	12542	7063	243.5	72692	1309.5

Table C.4. Variable and quasi-fixed input prices

Year	r_D	r_F	r_H	r_K	r_L
1960	0.674	0.897	3.7020	0.0066279	9.381
1961	0.781	0.909	3.9339	0.0063953	10.375
1962	0.858	0.914	4.2618	0.0062791	11.580
1963	0.855	0.920	4.8955	0.0061628	12.902
1964	0.854	0.933	5.5079	0.0063953	14.088
1965	0.856	0.936	5.9712	0.0072093	15.006
1966	0.865	0.947	6.6073	0.0076744	15.911
1967	0.875	0.940	7.2654	0.0077907	17.002
1968	0.917	0.957	7.9435	0.0081395	18.906
1969	0.931	1.007	9.9783	0.0091860	21.002
1970	1.000	1.000	12.0979	0.0100000	23.078
1971	1.067	1.085	14.0451	0.0097674	25.721
1972	1.107	1.118	16.0213	0.0093023	28.338
1973	1.328	1.190	17.5040	0.0104651	31.951
1974	1.477	1.770	20.5423	0.0127907	37.547
1975	1.525	1.957	23.3573	0.0119767	44.465
1976	1.682	1.950	27.2642	0.0123256	51.024
1977	1.884	2.094	32.3920	0.0127907	57.692
1978	1.882	2.258	38.7508	0.0127907	64.904
1979	2.011	2.529	44.7645	0.0126744	73.406
1980	2.185	3.242	51.8776	0.0158140	84.270
1981	2.495	3.674	58.7418	0.0173256	96.489
1982	2.772	4.088	71.1762	0.0204651	110.480
1983	3.105	4.347	80.7769	0.0183721	121.197
1984	3.343	4.631	87.1581	0.0180233	132.594

Table C.5. Technology and policy variables

Year	*RES*	*USP*	*REM*	*IVD*	*SAF*	*CR*
1960	62934	0.7010	2959.9	0	0	0.792982
1961	77467	0.7218	3227.8	0	0	0.750909
1962	99037	0.7418	3561.0	0	0	0.757407
1963	125081	0.7626	3936.7	0	3574	0.760377
1964	155426	0.7780	4290.2	19048	16965	0.698182
1965	162791	0.7926	4689.7	86895	28552	0.772581
1966	196020	0.8092	5160.4	107443	40008	0.706061
1967	224890	0.8188	5683.7	157442	53600	0.674627
1968	245914	0.8320	6167.3	210324	59200	0.728571
1969	243106	0.8430	6679.7	186072	63800	0.659494
1970	220502	0.8558	7210.0	217281	63900	0.595349
1971	246260	0.8584	7647.6	190290	71300	0.684524
1972	262782	0.8802	8074.7	160062	80900	0.780000
1973	279361	0.8970	8375.2	125889	82693	0.671111
1974	293301	0.9122	8885.0	101305	74574	0.571818
1975	318634	0.9168	9310.2	47780	71558	0.616505
1976	306828	0.9410	9711.9	61692	72024	0.550943
1977	324377	0.9488	10048.5	48326	76211	0.523636
1978	342230	0.9614	10360.5	54374	78935	0.580000
1979	373680	0.9768	10630.5	43573	80713	0.617431
1980	373698	1.0098	10941.9	110794	81956	0.560294
1981	466857	1.0144	11248.0	162126	82020	0.556376
1982	484231	1.0494	11602.9	179273	89020	0.540909
1983	513775	1.0774	11910.9	171582	86164	0.598101
1984	521330	1.0686	12222.3	164704	98456	0.584516

Table C.6. Land, weather, and price deflator variables

Year	*CL*	*PL*	*WEA*	*PGNP*
1960	19006.8	13062.7	192.50	0.6513
1961	19022.6	13133.9	-8.17	0.6734
1962	19098.4	13065.7	-26.25	0.7049
1963	18910.1	13113.2	64.42	0.7501
1964	18543.7	13280.7	-102.33	0.7812
1965	18267.3	13459.3	187.67	0.8026
1966	17946.0	13631.8	37.67	0.8258
1967	17573.0	13812.6	-127.48	0.8521
1968	17196.7	13874.7	80.33	0.8883
1969	17187.5	13908.2	-9.83	0.9467
1970	17047.1	13934.0	-56.30	1.0000
1971	16703.2	13933.3	26.17	1.0576
1972	16676.0	13882.8	84.83	1.1231
1973	16773.1	13759.1	-26.50	1.2105
1974	16957.0	13554.8	126.83	1.3453
1975	17012.1	13403.0	5.67	1.5256
1976	17131.2	13284.2	-5.00	1.6739
1977	17265.2	13073.5	153.17	1.8270
1978	17353.0	12978.1	34.00	2.0010
1979	17401.2	12912.5	164.33	2.2078
1980	17471.3	14269.4	44.67	2.4774
1981	17542.6	14157.5	174.33	2.7691
1982	17648.0	13993.0	56.33	3.1194
1983	17673.0	13892.0	-11.67	3.4151
1984	17811.0	13696.0	123.17	3.6603

Table C.7. Real cereals prices used in simulation

Year	French Prices	Actual U.S. Prices	Actual Exchange Rate	United States Prices in Francs: Actual Exchange Rate	United States Prices in Francs: Average Exchange Rate
1960	55.8881	8.0418	4.9026	39.4255	43.1762
1961	55.7976	8.3778	4.9013	41.0620	44.9803
1962	59.3675	8.5353	4.9001	41.8236	45.8258
1963	54.7882	7.4883	4.9020	36.7078	40.2049
1964	49.9617	6.1196	4.9001	29.9865	32.8559
1965	49.7999	5.9689	4.9015	29.2563	32.0468
1966	51.8702	6.6039	4.9518	32.7012	35.4563
1967	52.4189	5.5537	4.9085	27.2603	29.8178
1968	49.5954	4.9500	4.9481	24.4932	26.5766
1969	45.8910	4.6760	5.5583	25.9908	25.1056
1970	46.9676	4.8655	5.5205	26.8600	26.1229
1971	45.7419	4.3550	5.2245	22.7530	23.3823
1972	45.6252	5.4737	5.1210	28.0308	29.3882
1973	43.7278	10.1795	4.7085	47.9302	54.6538
1974	47.6205	10.2040	4.4445	45.3515	54.7851
1975	43.0393	7.7714	4.4855	34.8585	41.7245
1977	42.6230	4.5477	4.7050	21.3971	24.4168
1978	41.2874	4.9603	4.1800	20.7339	26.6317
1979	39.8665	5.4962	4.0200	22.0949	29.5093
1980	37.9168	5.4615	4.5160	24.6639	29.3225
1981	38.3156	4.3679	5.7480	25.1068	23.4513
1982	38.0330	3.7844	6.7250	25.4500	20.3183
1983	37.6968	3.6903	8.3475	30.8049	19.8133
1984	32.5538	3.1384	9.5920	30.1033	16.8499

Table C.8. Real milk prices used in simulation

Year	French Prices	Actual U.S. Prices	Actual Exchange Rate	United States Prices in Francs: Actual Exchange Rate	United States Prices in Francs: Average Exchange Rate
1960	58.7281	13.6613	4.9026	66.9759	73.3475
1961	55.8069	13.2443	4.9013	64.9142	71.1086
1962	56.5265	12.2627	4.9001	60.0886	65.8386
1963	57.1009	11.5519	4.9020	56.6275	62.0223
1964	56.0138	11.2273	4.9001	55.0151	60.2796
1965	54.0713	11.1385	4.9015	54.5956	59.8029
1966	54.2354	12.3100	4.9518	60.9567	66.0924
1967	54.2531	12.4510	4.9085	61.1158	66.8494
1968	51.8103	12.4670	4.9481	61.6878	66.9351
1969	49.4843	12.2560	5.5583	68.1228	65.8027
1970	51.4800	12.0677	5.5205	66.6197	64.7915
1971	54.5661	11.7302	5.2245	61.2846	62.9796
1972	56.9301	11.4225	5.1210	58.4946	61.3274
1973	54.5207	12.4659	4.7085	58.6958	66.9295
1974	52.7696	13.0862	4.4445	58.1617	70.2599
1975	51.9997	12.1215	4.4855	54.3711	65.0805
1977	50.4093	11.2439	4.7050	52.9025	60.3685
1978	50.7339	11.1957	4.1800	46.7978	60.1095
1979	49.6659	11.4871	4.0200	46.1783	61.6744
1980	47.7521	11.0901	4.5160	50.0830	59.5429
1981	47.2580	10.5325	5.7480	60.5407	56.5489
1982	47.1661	9.2074	6.7250	61.9198	49.4346
1983	46.7904	8.3978	8.3475	70.1008	45.0879
1984	45.7797	7.7660	9.5920	74.4912	41.6955

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