RURAL ECONOMY

Capital Formation, Technical Change, and Profitability in Prairie Agriculture

T.S. Veeman, A.A. Fantino, and Y. Peng

Project Report 95-09

Alberta Agricultural Research Institute Project No. 920199

Project Report

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ABSTRACT

This report comprises a number of related components focussed on the role of capital and capital formation in production, productivity and competitiveness in Canadian agriculture, concentrating on the Prairie region of Western Canada in the period 1970 to the early 1990s. The report includes the analysis of investment flows and capital stocks data, problems in measuring productivity, and an assessment of the relative roles of technological change and economies of scale in estimated productivity growth. In addition to the nature and extent of technical change, other features of the structure of production technology are analyzed by estimation of a translog cost function.

Input mix and investment data indicate an important increment in investment, resulting in a larger machinery stock in the 1970s and a modest increment in the stocks of capital related to agricultural land and buildings. Changes in the input mix result from the initial post-war substitution of capital for labour and an eventual rising share of materials inputs including agri-chemicals. The land input appears to change little and slowly. Land related investment and repairs also show a slow but steady growth over the period. In the 1980s, the labour share slowly rises, reversing its previous downward trend. The important increase in capital-related investments, particularly machinery, in the 1970s is followed by a considerable drop in the 1980s. Dis-investment appears to be taking place in the late 1980s and early 1990s. However, productivity and total output do not appear to be shrinking, and productive capacity does not appear to have been seriously affected in the short run by the lower levels of investment in the 1980s.

Cost function parameters, elasticities of derived demand for inputs, and Allen partial elasticities of input substitution are estimated in the report. Results indicate an increasingly rigid production structure in the 1970s and early 1980s, lower elasticities of derived input demand and reduced input substitution. Such trends suggest that technology in prairie farming was becoming a "technological package". This trend was modestly reversed in the late 1980s when a slowly changing input mix resulted from reduced use of chemicals and machinery. These changes may be related to changing economic conditions which generally favoured cost reduction as opposed to output expansion. The relatively slow response indicates the persistence of rigidities. It is not yet clear whether slightly lessened rigidity is the start of a new trend or only temporary. Testing functional properties of the cost function indicates rejection of homotheticity, of constant return to scale, and of Hicks neutrality.

The index number methodology for the empirical measurement of agricultural productivity is analyzed. A major problem is measurement of "durable" capital items. Aggregation or indexing procedures is another important conceptual issue. Given the conceptual superiority of flexible indexes we would recommend that Divisia-based or chained Fisher indexing be employed rather than traditional indexes such as the Laspeyres or Paasche. Our calculations suggest there is little practical difference in productivity estimates based on the Tornqvist-Theil approximation to the Divisia index as opposed to the Fisher "ideal" chained index. Total factor productivity, terms of trade and return to costs ratios are estimated. Although productivity growth nearly fully compensated for adverse movements in the terms of trade for

prairie agriculture over the entire postwar period from 1948 to 1991, it was much less effective in doing so in the 1980s and profitability deteriorated.

The evidence suggests that the farming system in Western Canada has been experiencing important transformations in the last two decades in our period of study. In terms of the structure of production technology, our findings indicate non-homotheticity, biased technical change, and a more important role for economies of scale. For productivity measurements, the use of flexible forms, such as Divisia or Fisher Chained procedures, is preferred. The agricultural system, having achieved a new ceiling in investment in the 1970s, went through a process of adjustments and correction in the second half of the 1980s. There was a reduction in the annual level of investments and a shrinkage in the capital stock, mostly due to a decline in farm machinery. Given technical change and data problems, it is difficult to say if the level of investment prevailing at the end of the period was sufficient to compensate for actual capital depreciation. Future data availability and further research may provide a more definite answer.

I. Introduction

The objective of this research is to address a number of issues related to the role of capital in prairie agriculture. The importance of these issues was highlighted by the depressed conditions of prairie agriculture since the mid 1980s which motivated the original research proposal. These issues included whether the sector was unduly depreciating its capital stock, adopting less technical innovation, experiencing slower growth in productivity, and losing its competitive edge. In part, the possible run-down in the stock of machinery, the reduced use of certain modern inputs, and reduced investment in land were a result of the economic conditions created by a depressed market.

The research is also motivated by the limited knowledge of and research on capital formation, as well as of the estimation of the flow of productive services associated with capital. These are certainly difficult areas, both conceptually and empirically. Many input data series on land, machinery and livestock are reported as stocks of capital. The approach commonly used is to estimate the capital input as some measure of the capital "consumed" or depreciated, and in the case of other durable inputs such as land, as the opportunity cost of using such assets for productive purposes. An obvious difficulty is that, for example, the estimated capital service flow of the land input, in a production or productivity analysis, necessarily diminishes merely because land values decrease in depressed times.

Technical change has long been recognized as a leading factor in agricultural development and competitiveness. Much technological change enters the agricultural production process in new capital inputs as farmers invest in land improvements, new and improved machinery, better livestock, and enhanced seeds and bio-chemical products. Technical change, in turn, is an important component in enhanced agricultural productivity, the most important influence affecting competitiveness in the long run. Of particular relevance is the decomposition of changes in productivity into pure technical change--that is, changes associated with new technologies-- and scale impacts on productivity , such as economies of scale. The latter refers to reduction in production costs due to an increase in the size of production activity. More to the point, there are economies of scale in a system if the increase of all inputs by a factor leads to a more than proportional increase in production.

It is therefore of importance to achieve a better understanding of the responsiveness of the agricultural production system to changing conditions, and of the complex relationships between capital investment, technical change and productivity growth, including estimation of the contributions of pure technical change and of economies of scale. Productivity growth, in turn, is critical to issues of profitability and competitiveness in prairie agriculture.

I.1 Objectives

The general objective of the research is to analyze capital formation, technical change, productivity growth and profitability in prairie agriculture. The study centres on the aggregate agriculture sector in the post-war period since 1948, with more emphasis on the 1980s and early 1990s.

Specific objectives of the research are:

1. To document statistically the changes in investment in prairie and Alberta agriculture and the associated changes in the input mix.

2. To investigate current approaches to the conceptual and empirical measurement of the capital stock, investment, and capital service flows in agriculture.

3. To analyze whether dis-investment is occurring with respect to key items of the capital stock such as machinery and land.

4. To consider major mechanical and bio-chemical forms of technical change in prairie agriculture, examining their links to the process of capital formation.

5. To analyze and empirically estimate the degree of input substitution, the elasticities of input demands, the extent of technical change, and the nature of scale economies in prairie agriculture using a "flexible form" production/cost specification.

6. To examine recent changes in productivity growth (using improved flexible index number procedures), the sectoral terms of trade, and the returns-to-cost ratio (an index of profitability) in prairie agriculture.

7. To make policy recommendations regarding capital formation, technical change, and input use in prairie agriculture.

I.2 Format of the Report

The report is organized in four main sections in addition to the introductory section. Section II includes a brief overview of the capital input in Canadian agriculture with special reference to the prairie region and the province of Alberta. A more detailed statistical examination of trends in capital stocks, investment expenditures, and capital input prices is presented. Major input categories of land and buildings and machinery are included, as well as specific items when more disaggregated data are available.

Section III includes empirical research work and results pertaining to the econometric estimation of a trans-log cost function and analysis of the structure of agricultural production and the role of the capital input in the input mix.

In Section IV, technical change in agriculture and its effects on production and productivity are considered in relation to the capital input. Empirical measurement of productivity by means of several improved indexing procedures is undertaken and the results compared. Productivity growth is related to profitability. Estimated productivity growth is also decomposed into pure technical change and economies of scale effects. Finally, in Section V, the conclusions and implications of the research are presented.[1]

II. Capital Input, Investment and Capital Formation in Prairie Agriculture.

In this section the role and nature of the capital input in agriculture production is introduced. A brief statistical review of the available capital related data, chiefly Statistics Canada and Canada Census data, is presented. The objective is to statistically document changes in capital stocks in prairie agriculture. Reference is also made to the Canadian and Alberta agricultural sectors. In addition to stock levels, investment expenditures in capital items are also reported and analyzed, particularly in the most recent period.

Agriculture production, as most production processes, involves the use of capital as a productive input. The input mix in prairie agriculture may be described on the basis of the following types of inputs: land, machinery, labour, chemical materials, and non-chemical materials. Obviously such a classification involves a degree of aggregation of input types. Nevertheless, it is useful for the purpose of a general description of the input mix in agriculture. Figure 1 charts the relative contributions of each type of input to total cost--that is, the "cost shares"--in prairie agriculture. The labour input, which comprised the largest cost share in the 1950s, has decreased considerably relative to other inputs. This is mostly due to an extensive process of substitution of capital for labour during the 1950s and 1960s. In the 1980s, however, the labour share has been slowly increasing reflecting a larger proportion of hired labour on farms. Also to be noted is the relative growth of chemical materials in the input mix and expansion of non-chemical materials in the 1970s. Machinery has also experienced growth although a more modest one. The participation of any input in total cost is composed of two factors: the quantity utilized and its respective price. Changes in relative prices alter the cost shares even when relative quantities are unchanged. In Figure 2, the evolution of input prices over the post-war period is traced. The rapid escalation of prices during the inflationary 1970s is to be noted. Land prices rose the most in the 1970s which explains a large part of the associated increase in land shares in cost in Figure 1. It is also interesting to note the continuous rise of machinery prices.

Some inputs, for example, fuel or fertilizer, become used up, completely "consumed",

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[1] It is to be noted that a portion of Section III has been presented as a contributed paper (Fantino, Veeman, and Peng, 1995) to the Annual Meeting of the Canadian Agricultural Economics and Farm Management Society in Ottawa in July 1995. Also, Section IV is largely based on a contributed paper (Fantino and Veeman, 1994) selected and presented at the International Conference of the International Association of Agricultural Economists (IAAE) held in Harare, Zimbabwe, August 1994 and to be published by the IAAE.

Figure 1. Input Cost Shares, Prairie Agriculture

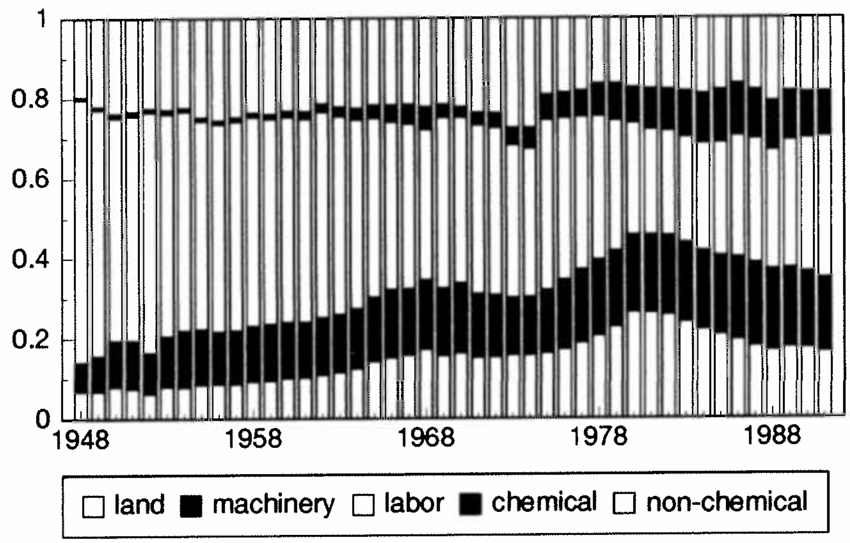
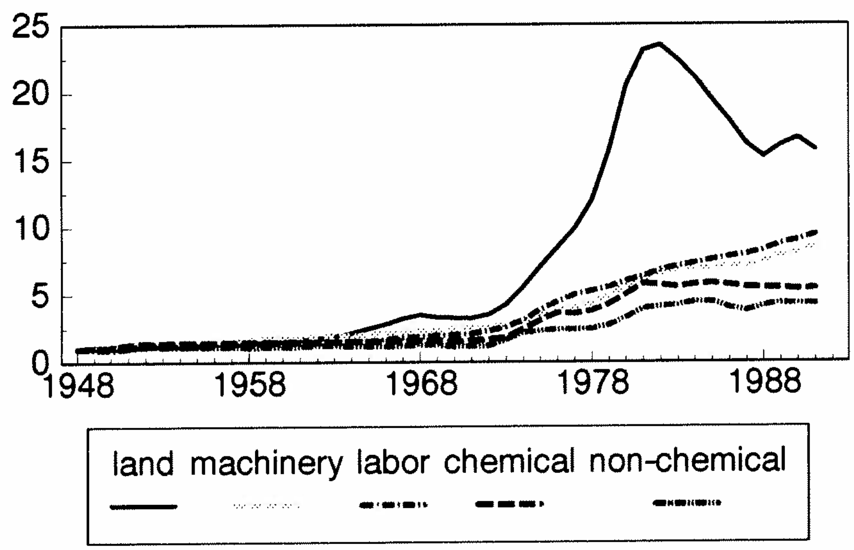


Figure 2: Input Price Indexes, Prairie Agriculture



during the production cycle. Capital, on the other hand, refers to any asset contributing to production which is not entirely used-up or consumed in a productive cycle. Capital is therefore a "durable" input which, being an asset, has value in the market and its use as an input involves a financial dimension. Capital, generally speaking, originates from the process of investment so that capital stocks are the result of investment expenditures.[2]

Capital assets actually enter agriculture by rendering productive services. From the point of view of production economics, estimation of the flow of services emanating from capital stocks is more important than the stocks themselves. This means that the productive efficiency of capital assets is the relevant measure of the productive services associated with the use of capital. Moreover, many capital assets are subject to depreciation over time, for example, machinery, vehicles and fixed facilities such as buildings. Other assets, such as land, may be considered free from this type of depreciation.[3] From an economic point of view, therefore, the definition, proper measurement, and productive role of capital involve many conceptual and empirical problems. Some of these problems are addressed in this and following sections. An overview of the statistical data related to capital stocks and investments follows. Sub-section II.2 considers the stocks of depreciable assets and it includes a re-estimation of the capital stock in prairie agriculture by the method of perpetual inventory based on investment expenditures and depreciation of assets.

II.1 Capital Stocks and Investment Trends in Prairie Agriculture

This statistical review is based on available data on capital stocks and on investment expenditures. These data are originally generated by primary collection (surveys) of current values of capital assets on farms. The data therefore constitute an important source of information. Capital assets were already classified as depreciable and non-depreciable assets. In this section, a further break-down is based on the categories defined by Statistics Canada as follows: 1) Total Capital; 2) Land and Buildings; 3) Machinery and Implements; 4) Livestock and Poultry Capital. Data can also be obtained for more disaggregated categories such as Land Values and Buildings Values, for example. Investment, in turn, is presented as Gross Fixed Capital Formation Total; and expenditures are classified as Building and Construction, Engineering Construction, and Machinery and Equipment. The last item is broken down into

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[2] In certain type of durable productive assets, a portion of value may result from factors other than investment. This is the case of natural resources, such as land, used in agriculture. Natural resources have to be developed in order to be used, which involves investments, for example, expenditures in land improvements in agriculture. Part of their values reflect such investments. Nevertheless, another portion of the resulting asset values comes from different types of rents, for example, differential rents and scarcity rents.

[3] Land may also depreciate from its use in agriculture if its natural fertility is diminished with the process of production. Natural environmental conditions may also contribute over long periods of time to land depreciation.

Farm Machinery, Passenger Vehicles[4], and Commercial Vehicles.

Figure 3 and Figure 4, which correspond to Canadian and Alberta agriculture respectively, portray the current value of the stock of total farm capital and of three important components of farm capital: land and buildings, machinery, and livestock. Super-imposed are Canada Census values. Given the almost complete coverage of the Canadian Census, these Census values are considered bench-marks. Land value is the principal component of total farm capital. It is also the one component with the largest variations. Most of the variation in Figure 3 is due to changes in asset prices. Total capital follows the land value curve closely since variations in machinery values and in livestock are much less pronounced. Similar features and comments apply to Alberta agriculture (Figure 4). Total farm capital follows the variations of land values even more closely than in the Canadian case. This variability may be attributed to several factors: at a given moment land is available in a more or less fixed amount and variations over time are slow; land is a residual claimant of farm output and therefore its value reflects current and expected conditions of the farm business; and land is also an inflation hedge, a financial and investment asset to a much larger extent than other farm capital assets.

The effect of current prices on the measured capital stock are very significant. In order to obtain a clear idea of the actual stock of capital we need to obtain estimates of such stocks in real terms, that is to say, a value measure which may represent or at least approximate the stocks quantitatively. Ideally, a complete physical inventory of each class of capital items would be necessary for a depiction of a realistic picture of capital stocks. Even so, problems may arise when evaluating changes in those stocks if changes in the relative proportions of the different classes are present, which is likely to occur. The problems of comparing and aggregating items of a different nature are well known. An aggregation procedure is always needed.

A simple procedure which gives an approximate measure of the real level of capital in agriculture can be obtained by deflating capital stock figures by a price index. In this manner a constant dollar valuation is achieved which represents a quantitative measure of the amount of physical capital in existence. Such a measure can be called an implicit quantity index or measure. The results from such calculations are presented in Figures 5 and 6 for Canada and Alberta respectively. The measures for land capital and livestock capital show small variations over time. Land in Canada is virtually constant, and in Alberta the measure exhibits a slight increasing trend. Livestock capital features some fluctuations associated with the cattle cycle around a long run rising trend, particularly for Alberta. The larger variations occur in the machinery and implement capital measure which exhibits a rapidly increasing trend in the 1970s, followed by a slowly decreasing trend from the mid 1980s to the end of the period.

We have already related the stocks of capital to investment, which in turn is closely associated with the behaviour of investment expenditures. Constant dollar value of investment

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[4] Passenger vehicles are not included in this analysis since it is assumed they play a minor role in production.

Figure 3. Current Value of Capital and Three Components for Canadian Agriculture

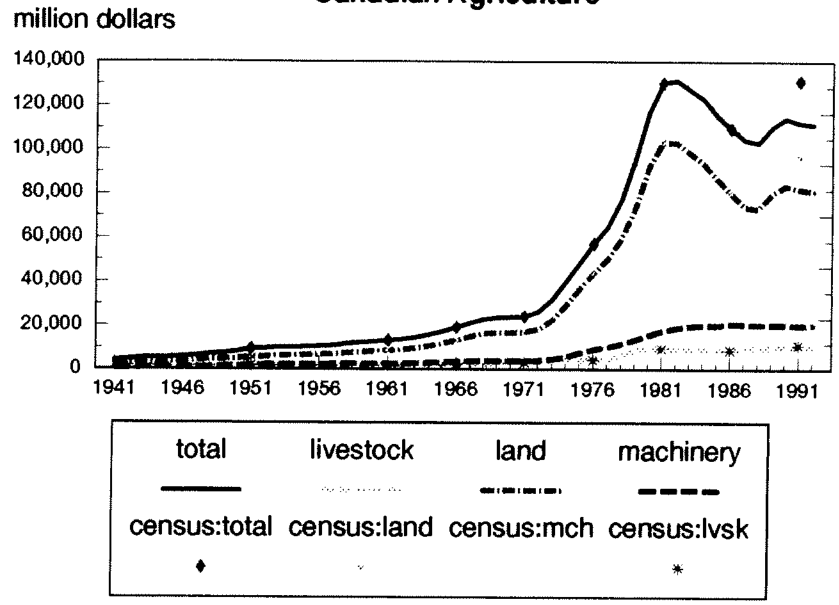


Figure 4. Current Value of Capital and Three Components for Alberta Agriculture

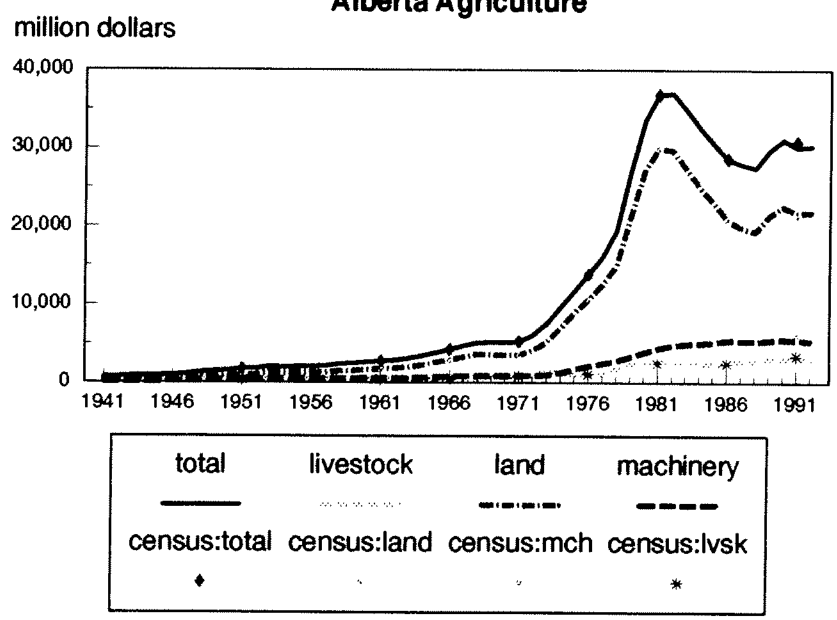


Figure 5. Indexes of Constant Dollar Value Total Capital (1971=1) and Three Components for Canadian Agriculture

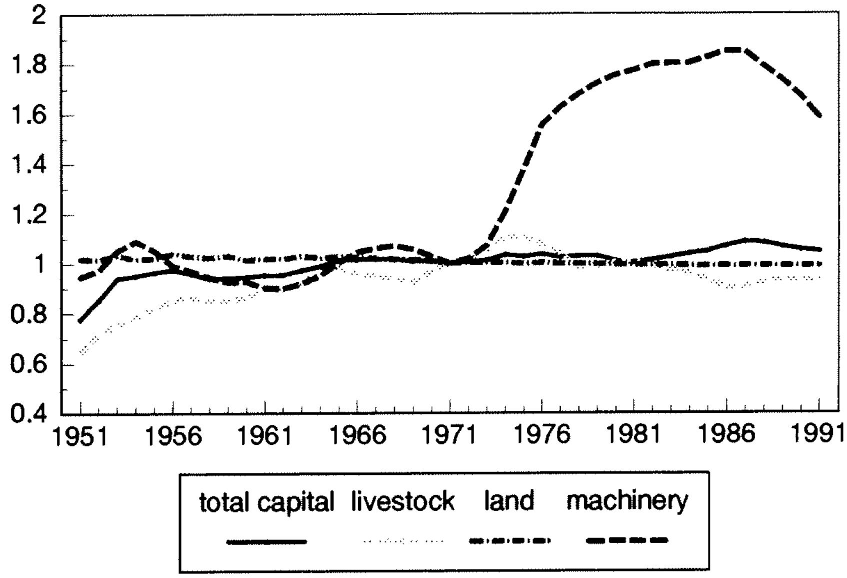
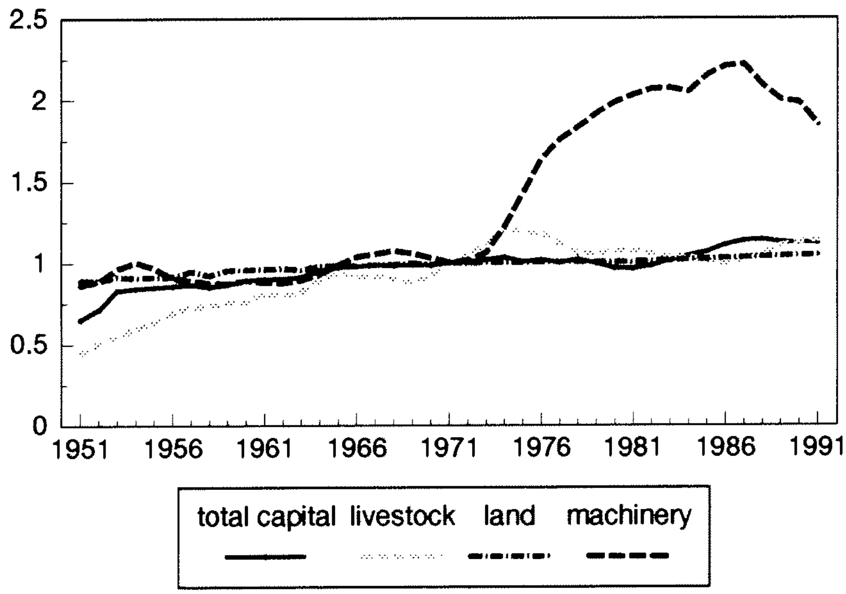


Figure 6. Indexes of Constant Dollar Value Total Capital (1971=1) and Three Components for Alberta Agriculture



expenditures, which provides a quantitative estimate of real additions to the stock of capital, are calculated for Canada and the prairies. Figures 7 and 8 plot constant dollar value capital investments in machinery and vehicles and in building and engineering construction, respectively, at 1986 prices, for Canadian agriculture. In the post war period investment in farm machinery, the most important item in Figure 7, peaks in the late 1940s, in the mid 1960s, and in the late 1970s. After 1980 the level of investment drops sharply to reach a more stable level in the early 1990s. A similar pattern occurs in Figure 8 plotting investments in buildings and in engineering construction, a land related investment. The last peak occurs around 1979, followed by a significant drop in investments to the level of the mid-1950s, which nevertheless is not so sharp as the corresponding drop in investments in machinery. Finally, Figure 9 depicts investments in machinery and equipment for prairie agriculture. In Figure 9, the same pattern is observed: investment peaks around 1978/1979, then falls sharply thereafter to reach a more stable level in the late 1980s and into the 1990s, at a level comparable to that prevailing in the late 1950s.

The data appear to demonstrate clearly a considerable reduction in the level of investment in Canadian and Prairie agriculture during the 1980s. Whether or not these trends represent a process of dis-investment taking place in agriculture is not clear from these data alone. Obviously a reduction in investment levels certainly means that the capital stock cannot be growing as fast as before, at least in the short run.[5] In the period under consideration some changes in prices of capital items took place as we will analyze below. Nevertheless, it seems clear that the reduction in investment goes beyond what compensation might be expected from changes in capital prices alone, and it seems fair to assume that the capital stock is not growing as fast as in the mid-1970s. Dis-investment, however, requires that the rate of growth of the capital stock be negative. Dis-investment occurs when actual physical depreciation of the capital stock is larger than capital replacements introduced in agriculture by investments. If the levels of observed investments in the 1990s is enough to replace depreciated productive assets, then the capital stock would be maintained approximately constant and no dis-investment would exist.

Figure 9 also presents the annual machinery depreciation series estimated by Statistics Canada and converted to constant dollar terms. As can be seen in Figure 9, the level of the investment curve is located above the depreciation curve from 1956 to 1982. This strongly suggests a positive net investment in that period since additions to the machinery stock are larger than withdrawals. This is particularly so since the depreciation series, given the way it is estimated, is likely to be an overestimation rather than an underestimation. This situation reverses in the years after 1982, which exhibit higher levels of depreciation than of investment. The gap between the two grows considerably after 1982 and levels out in the late 1980s. This would suggest a process of dis-investment in machinery. Nevertheless, Figure 9 is likely to

[5] In the short run the amount of investment needed for a given increase in the stock of capital cannot change very much. In the long run however, technological change and productivity advances may reduce the prices of capital items and therefore make a given investment go further in terms of additions to the capital stock.

Figure 7. Constant Dollar Capital Investment at 1986 Prices in Farm Machinery, Pass. Vehicles and Comm. Vehicles in Canadian Agriculture

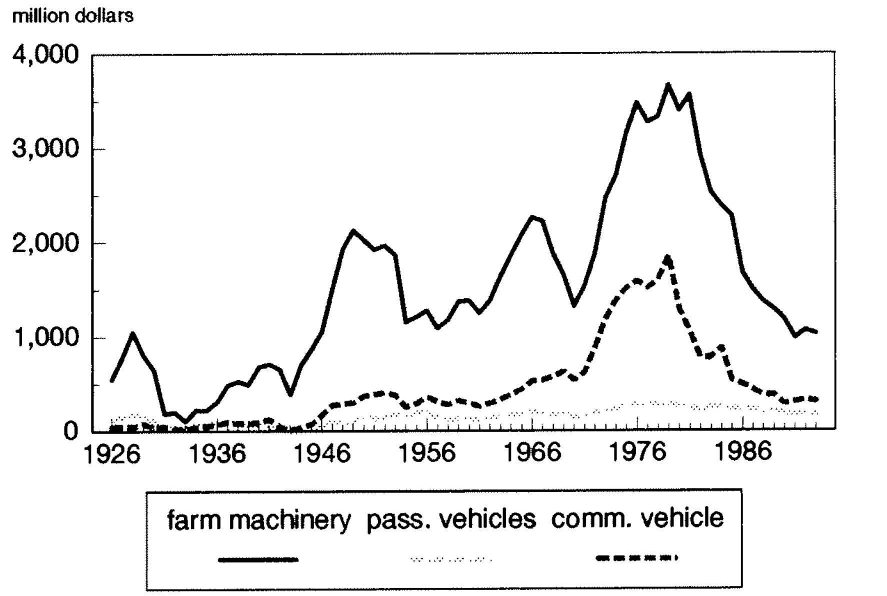


Figure 8. Constant Dollar Capital Investment at 1986 Prices in Building Construction and Engineering Construction in Canadian Agriculture

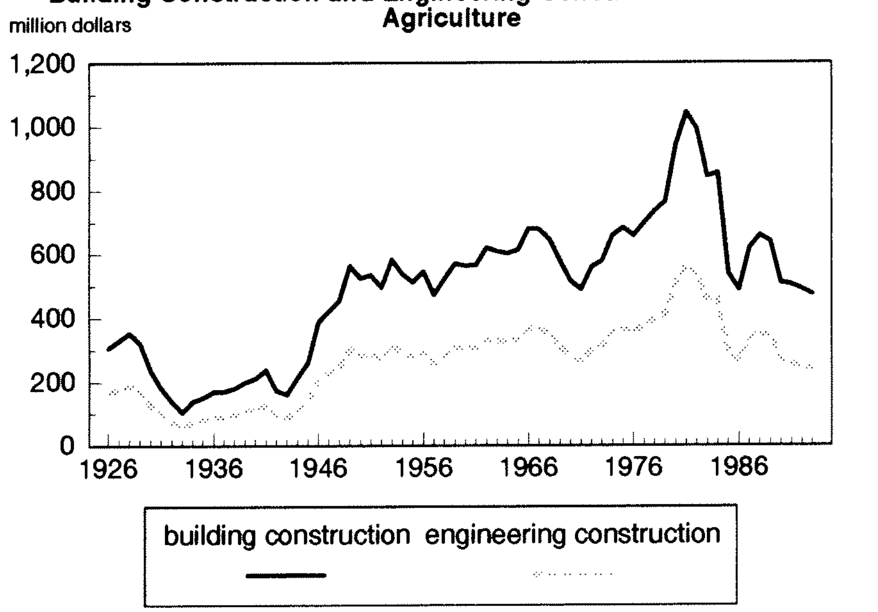
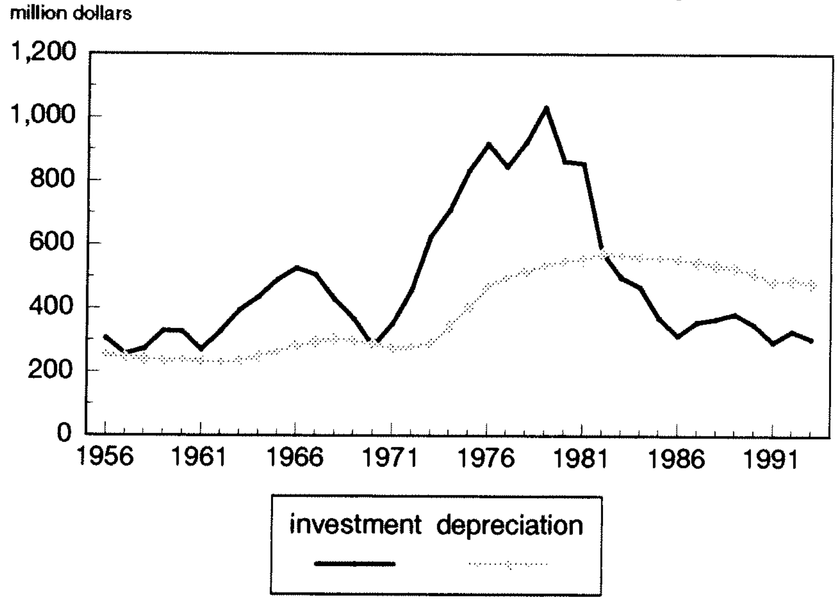


Figure 9. Constant Dollar Capital Investment and Depreciation at 1971 Prices in Machinery and Equipment in Prairie Agriculture



exaggerate the actual gap between depreciation and investment, given the suspected overestimation of the depreciation series. The actual gap is likely to be smaller than that indicated in Figure 9, which translates to a more modest level of dis-investment.

This dis-investment does not appear to be very significant if allowance is made for a process of substitution of new improved machinery and facilities for old vintage machinery and buildings and the associated technical improvements and enhanced productivity. Such a process surely is taking place. All in all, the data seems to indicate that dis-investment does not appear to be very significant.[6]

Finally, we turn our attention to the behaviour of capital item prices in prairie agriculture which can provide useful information. Figures 10 plots price indexes of the following investment items: all inputs, buildings, machinery, and combines. The impact of the inflationary 1970s is clearly shown as well as the more recent price increases in the late 1980s and 1990s. Figure 11 shows the period 1986 to May 1995 in more detail. Consider the period 1992 to May 1995. In such a relatively short period of time given the non-inflationary environment, these input prices

[6] See Section IV. A reduced level of investment may impinge negatively on the rate of incorporation of technical change embodied in machinery and other capital items. This may be related to the finding in Section IV that an increasing portion of the rate of growth in productivity is related to economies of scale at the expense of pure technical change.

Figure 10. Capital Input Price Indexes, Canadian Agriculture, 1961 to 1991, 1986=100

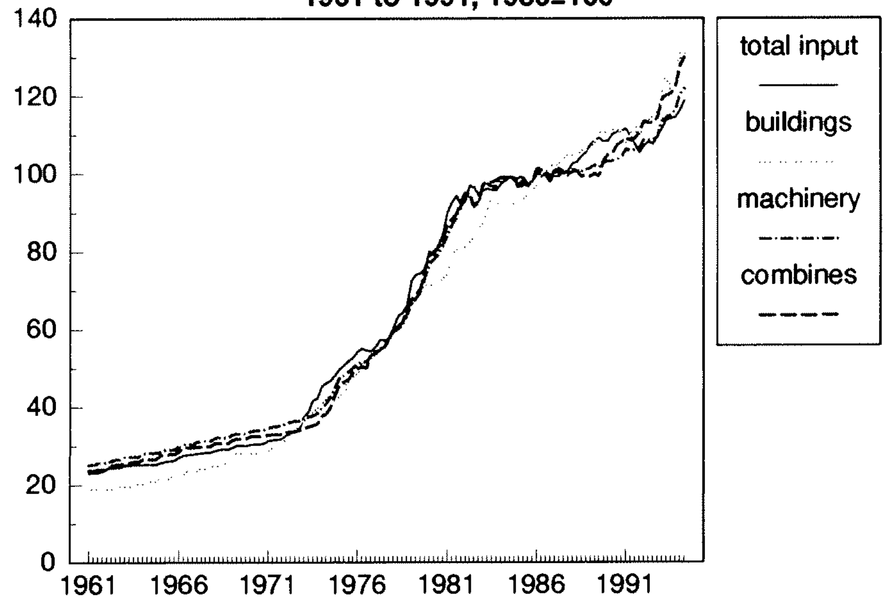
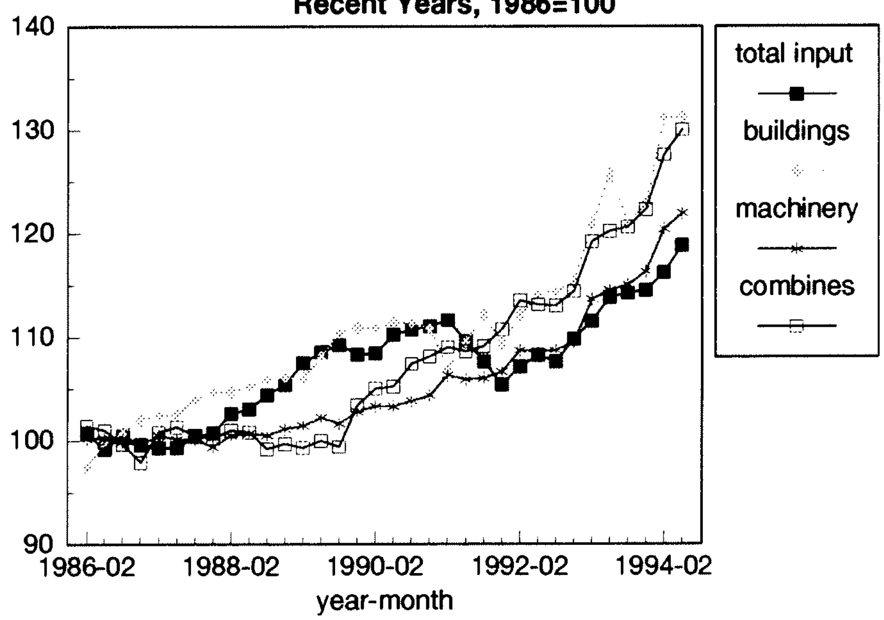


Figure 11. Capital Input Price Indexes, Canadian Agriculture, Recent Years, 1986=100



have increased by 10 to 15 percent. Undoubtedly, this fact contributes to making investments in such items more financially difficult for many farmers. Farms with above average profitability would be in a much better position to undertake such investments. It is remarkable that buildings and combine prices are climbing faster that the aggregate of all input prices. This may be an indication of technical factors at work. Price increases are the result of many factors, but price differentials among closely related items such as all machinery and combines in a given market are to be expected if technology contents and technical change affect such items differently. If new buildings, facilities, and combines available to agriculture incorporate enhanced features and improved efficiency, such items would probably be priced higher. A combination of technical change and increased financial difficulties for many farmers in the period may explain the relatively low level of investment in the late 1980s and 1990s. All these factors will be of interest in interpreting findings in Sections III and IV, in particular those related to the technical features of the structure of production and to the existence of economies of scale in prairie agriculture.

II.2 Investment, Capital Formation, and Measurement

Capital formation, we have argued, is the result of investments over time. Such investments involve expenditures on durable capital items such as machinery and implements and construction of buildings and facilities. On the other hand, although capital is not totally consumed in any one cycle of production, it is recognized that over time individual items suffer wear and tear and otherwise lose their productive usefulness. This constitutes the process of depreciation which characterizes durable production inputs. Thus, the capital stock is constantly augmented by the process of investment and constantly diminished by the process of depreciation. The resultant balance between both processes in each period extended indefinitely into the past is the Perpetual Inventory Method of capital stock estimation. In this sub-section this method is used to estimate the capital stock of depreciable assets in agriculture. The procedure follows Jorgenson (1974). In the second part, the dual price model suggested by Ball (1985) is presented.

II.2.1 Perpetual Inventory Method

In the durable goods model in Jorgenson (1974), durable goods decline in efficiency with time so that replacement is required to make up the loss in efficiency as well as actual physical disappearance of capital items and, in this way, maintain productive capacity. Define K_t as the capital stock, I_t as investment expenditures, and R_t as the replacement requirements or depreciation for the durable good, at the end of the time period t. The change in capital stock is given by the increase due to acquisition of investment goods less the reduction due to replacement requirements, or

$$K_t - K_{t-1} = I_t - R_t \, . \tag{1}$$

Replacement requirements R depend on both the stock of capital and the rate at which the stock depreciates and its efficiency declines. A most commonly used assumption for the efficiency distribution over time is geometric in which the rate of replacement or depreciation, denoted by δ, is constant over the entire time period. Replacement requirements, then, are proportional to the capital stock at the beginning of the period, as follows:

$$R_t = \delta K_{t-1} , \tag{2}$$

so that

$$K_t - K_{t-1} = I_t - \delta K_{t-1} . \tag{3}$$

This relationship, which Jorgenson terms the perpetual inventory method, can be used to measure the capital stock, given the rate of depreciation and amount of investment at each point in time.

In order to apply this methodology, we need to determine the rate of depreciation (delta) and to collect data on annual investments. Moreover, we assume an initial point of 1925, that is to say, capital formation begins in that year. This assumption obviously introduces an error of estimation which may be significant in the initial years of the series. After 30 or 40 years, however, any initial capital in existence would have mostly depreciated and may be ignored. Constant dollar fixed capital formation for each category was retrieved from Statistics Canada's data base CANSIM annually from 1926 to 1993. The rate of depreciation is defined on the basis of estimated lengths of useful life of capital items. The items are considered in use until depreciation reaches a high percentage of its value, the remainder being the residual or "salvage value".

Table 1 presents rates of depreciation resulting from different lengths of life and salvage values. Rates of depreciation are very high for short lives and low salvage values as illustrated in this table. It appears reasonable to assume an intermediate situation. For machinery, 15 years and 10 % are adopted as length of useful life and residual, respectively. For buildings, the numbers are 45 years and 5%, respectively. Net capital stock figures in constant dollars for the total of machinery, implements and vehicles were collected for the period 1926-1993, as well as the three component series of farm machinery, passenger vehicles, and commercial vehicles.

We adopt Statistics Canada definitions[7] for the average life-time: 15 years for farm machinery, 8 years for passenger vehicles, and 10 years for commercial vehicles. The resulting depreciation rates are: 0.1423 for farm machinery, 0.2501 for passenger vehicles, and 0.2058 for commercial vehicles.

Net constant dollar capital stock estimates can then be calculated iteratively by the perpetual inventory formula (3) for each year. These series of constant dollar net capital stock multiplied by their corresponding price indexes, give us their current values. Adding the three

[7] See Cat. 13-211.

Table 1. Depreciation Rates of Capital Items

			Machinery			
Life (years)	10	12	15	16	18	20
5% residual	0.25887	0.22092	0.18104	0.17075	0.15332	0.13911
10%residual	0.20567	0.1746	0.1423	0.13404	0.12008	0.10875
20%residual	0.14866	0.12551	0.10174	0.0957	0.08553	0.07732
			Buildings			
Life (years)	25	30	35	40	45	50
5% residual	0.11293	0.09503	0.08203	0.07216	0.06441	0.05816
10%residual	0.08799	0.07388	0.06367	0.05594	0.04988	0.04501
20%residual	0.06235	0.05223	0.04494	0.03944	0.03513	0.03168

series up form the total current value net capital stock for machinery and implements (CMCH) for Canadian agriculture. CMCH is plotted in Figure 12 which also includes Statistics Canada annual estimations [8] as well as Canada Census data, which can be regarded as bench marks, and StatCan estimates by geometric, straight line, and delayed depreciation methods retrieved from CANSIM (matrix No. 6543). Figure 12 shows that our estimations approximate Census data quite well, except for the last few years of the period. Similar estimation has also been conducted for prairie agriculture, and the results are displayed in Figure 13.

Since the investment data for the Prairies is only available for total machinery and equipment, choosing the average years of life for the items is not so straightforward. Therefore, we apply different lengths such as 12, 13 and 14 years respectively, and compare the current values of net capital stock based on these life times with Census data (Census) and Statistics Canada annual estimations. The results indicate that, overall, 13 years is the most appropriate time to depreciate 90% of the total capital prior to 1980. But after that year all three alternatives underestimate the capital values, relative to the Census data, which means each method depreciates too much. To reduce their distances away from the Census bench-mark, we have to use lower depreciation rates which means longer life-times for depreciable capital items. A similar effect is apparent for Canada as a whole: Figure 12 indicates that underestimation of the machinery capital stock is also present for Canadian agriculture since the late 1980's. Finally, these results can be interpreted as implying that farmers have kept their machinery and

[8] Statistics Canada adjusts its geometric estimation in order to make it consistent with the Census data.

Figure 12. Comparison of Current Value Machinery and Implements among Different Measurements for Canadian Agriculture

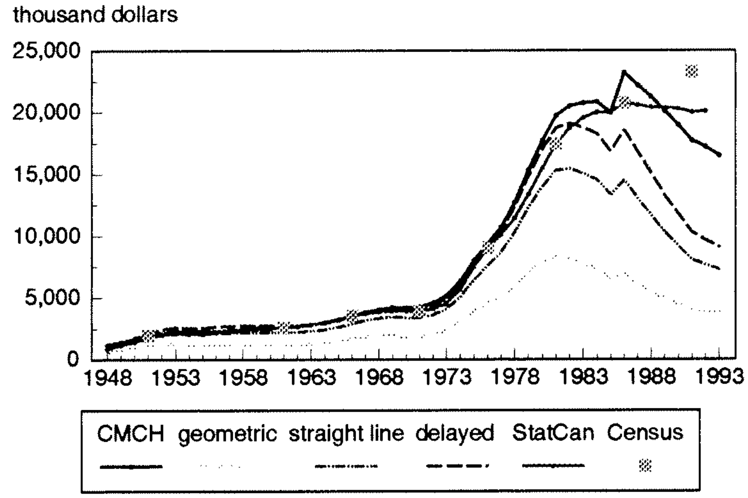
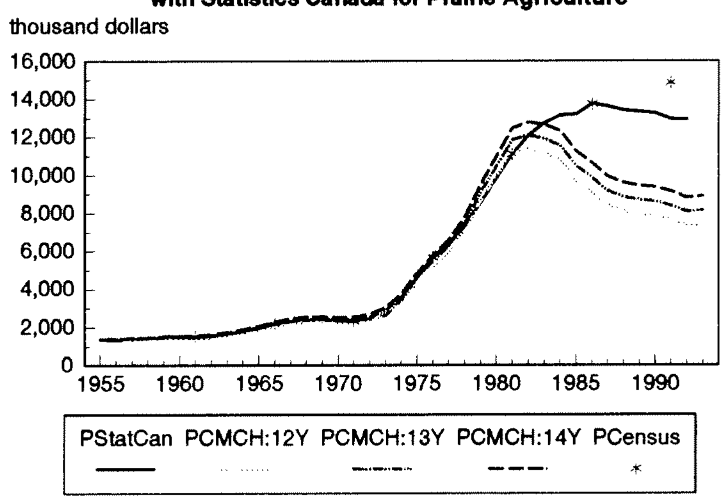


Figure 13. Comparison of Current Value Machinery and Implements with Statistics Canada for Prairie Agriculture



equipment in service longer than usual in the last decade, using machinery more intensively. This would mean a higher utilization of existing capacity, which translates into reductions in overcapacity. Naturally, technical changes, in the use of inputs and cultural practices, must have occurred concurrently. As we will see in latter sections, economies of scale are also involved.

II.2.2 The Dual to the Perpetual Inventory Method

The durable goods model is amenable to the price-quantity duality approach. The price model, which is the dual to the Perpetual Inventory Method, describes the relationships between the price of acquisition of investment goods P_{At} to the rental price of capital service P_{Kt} as

$$P_{Kt} = P_{A,t-1}r_t + \delta P_{At} - (P_{At}-P_{At-1}), \tag{4}$$

where r_t is the nominal rate of return to capital.

To measure the rental price of capital service, we have to determine r_t first. While Ball (1985) points out that using interest rate on investment or mortgages as a proxy for return to capital may be appropriate in the long run only, he suggests a method to measure r_t for U.S. agriculture. His proposed method assumes that the outlay on total capital services is the sum of outlays on each individual capital input, which in turn is the product of the rental price of capital service for this item and the corresponding capital stock. The nominal rate of return r_t is calculated as the ratio of property compensation on total capital less depreciation, plus capital gains, and less property tax, to the total value of capital at the beginning of the period. Ball (1985) determines property compensation from the U.S. national income accounts as follows: national income originating in farming + capital consumption allowances + indirect business taxes + government payments to non-operator landlords - labour compensation - imputed compensation of self-employed and unpaid labour. Some modification would be necessary to apply this approach to Canadian data in order to derive property compensation. Once r_t is measured, one could derive the rental price of capital service for each individual input by (4), and the value of the service flow as well.

II.3 Capital Formation and Technical Change

Capital is an important input in agriculture. As has already been pointed out, capital participates in agriculture by providing a flow of productive services. It is this flow of services which measures more accurately the productive contribution of capital, that is to say the capital input that enters into agriculture. There is, however, another different role that capital, through the process of investment, may play in the development of agriculture. The introduction of certain changes in productive technology may require the use of some definite capital items, whether in the form of new machinery and facilities or in the form of working capital necessary for the acquisition and use of inputs such as fertilizers and seeds. Besides, the investment in new machinery may be necessary for the introduction of some cultural practices or for better timing of fields operations. Moreover, investment in new capital items is an opportunity to introduce technical changes that are incorporated in those capital items, or "capital embodied technical change". Even a mere change in factor proportion may involve investment requirements. Thus, besides being a production input, capital is also a vehicle for the diffusion of innovations and technical change which in turn would be reflected in improved productivity and competitiveness.

In the period under study, the first manifestation of this role of investment in capital items is the process of mechanization of agriculture which took place after World War II and whose initial phases were largely completed in the 1960s. This was basically a process of substitution of capital in the form of machinery for labour and animal power. Continuing into the 1970s this type of investment driven input substitution, including capital investment in ever larger and more powerful machinery, the introduction of more sophisticated combines and dairy equipment, electrification, etc, along with the technical changes associated with them, have transformed prairie agriculture considerably. The drop in labour input had reduced unit costs and helped to produce a relatively high rate of productivity growth over the period. This represents a clear link between capital formation and technical change.

The second form of technical change is of the bio-chemical type, initially represented by the intensification in the use of agri-chemicals: fertilizers, herbicides and other pesticides. Increased usage of agri-chemicals in the prairie provinces started in the late 1950s and escalated in the 1960s and 1970s. This new wave of technical change had considerable effects on output and productivity in that period; a large share of output and productivity growth is strongly associated with the increases in the use of agri-chemical inputs in prairie agriculture (see Veeman and Fantino, 1994b, and Veeman and Fantino 1990).

Prairie agriculture in the 1980s has entered another phase of technical change, predominately of the bio-chemical type, where some specialized inputs are prominent. In this report these inputs have been pooled together with energy inputs in the non-chemical materials category. This is the case of seeds, for example, which farmers are now purchasing more and more from specialized firms which supply seeds of specific varieties selected and conditioned for vigour and sanitation. Similar trends are present in the areas of livestock feeds. Mechanical innovations are mostly further enhancement of existing technologies, with machinery incorporating improved control accessories and features. In the livestock sector, the use of some bio-technology products such vaccines, semen, and other animal health related inputs are of increasing importance.

Most of the inputs involved in the last two categories are related to capital, although in a different manner than machinery and land. The capital outlays that are made in each productive cycle constitute what is usually termed "operating capital". Both fertilizer and seeds are not "durable" capital; they are consumed in the process of production. Nevertheless, there is a time dimension attached to their use and the returns they provide--that is to say, outlays in operating capital do have a financial aspect for farmers. The adoption of these innovations, by increasing the need for operating capital, represent an increased expenditure in "out of pocket money" for farmers. The returns on such investments, is of course, the increased output produced by the new input mix that includes the innovations. These expenses have been rising since the 1970s suggesting a more important role of operating capital as a vehicle of technical change. Further analysis of technical change and economies of scale will be made when considering, in following sections, the nature and structure of production technology and total factor productivity in prairie agriculture.

III. Capital and the Structure of Production Technology in Prairie Agriculture

The objective of this section is to study the structure of agricultural production technology in the Canadian prairies. The structure of production technology involves the relationships between inputs and output, and among inputs themselves, as embodied by the production function. These comprise various important features of the production function, including economies of scale, biases of technical change, input substitution possibilities and input derived demands. The analysis of these features is of great assistance in achieving a better understanding of the relationships between the capital input and other inputs in prairie agriculture. The study of the structure of production technology has gained momentum since the introduction of duality based estimation procedures. In particular, the use of translog cost function estimation is a general, less restricted procedure providing useful estimates of straightforward interpretation. Such flexible form estimation procedures have been extensively used to study the structure of production in agriculture. The objective is to study the structure of production technology in prairie agriculture by means of the above mentioned procedures. The study considers the aggregate agricultural sector--that is, the aggregate of both the crops and livestock sub-sectors.

In contrast with similar studies, this study concentrates on the prairie provinces of Western Canada, a more homogenous area comprising the provinces of Manitoba, Saskatchewan and Alberta. The period covered, 1948-1991, includes information from the late 1980s and early 1990s. In addition, the study is aimed at supplying information on important properties of the production technology in agriculture such as homotheticity, economies of scale, and the biases of technological change. Following this introduction the section is organized in three sub-sections, which deal respectively with the methodology utilized, empirical results, and hypothesis testing. Finally, conclusions are advanced in IV.4.

III.1 Cost Function Estimation: Methodology and Data

As outlined above, a translog cost function, a dual approach to production analysis, is employed to analyze agricultural production technology in the Canadian prairies. There are several advantages associated with the use of a translog functional form, a major one being that a translog function is a flexible aggregation form.[9] We assume that the aggregate agricultural sector produces a single output and uses multiple inputs, and that the minimum total cost *C*, expressed

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[9] Chambers (1988), Chapter 5. The translog function was proposed in Christensen, Jorgenson and Lau (1971).

in logarithmic form, is a twice differentiable analytical cost function of input prices, output level, and a technological proxy T. More specifically, T is defined as a time trend, and, therefore, technological change is represented by a shift over time of the cost function. Further, the functional form for C is defined as the translog cost function, an approximation by Taylor expansion of the general cost function defined above, which can be written as:

$$\begin{aligned} \ln C = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln P_i + \alpha_y \ln Y + \alpha_t \ln T + \frac{1}{2} \sum_{i,j=1}^{n} \gamma_{ij} \ln P_i \ln P_j + \sum_{i=1}^{n} \gamma_{iy} \ln P_i \ln Y \\ + \sum_{i=1}^{n} \gamma_{it} \ln P_i \ln T + \frac{1}{2} \gamma_{yy} (\ln Y)^2 + \gamma_{ty} \ln Y \ln T + \frac{1}{2} \gamma_{tt} (\ln T)^2, \end{aligned} \tag{5}$$

where $\alpha_i, \alpha_y, \alpha_t, \gamma_{ij}, \gamma_{iy}, \gamma_{it}, \gamma_{yy}, \gamma_{ty}$, and γ_{tt} are the parameters to be estimated. The symmetry constraints $\gamma_{ij} = \gamma_{ji}$ $(i \neq j)$ are imposed to reflect the equality of the cross partial derivatives of *lnC* with respect to prices. For the cost function to be homogeneous of degree one in prices, the following restrictions are required:

$$\sum_{i=1}^{n} \alpha_i = 1, \; \sum_{i=1}^{n} \gamma_{ij} = 0, \; \sum_{j=1}^{n} \gamma_{ij} = 0, \; \sum_{i=1}^{n} \gamma_{iy} = 0, \; \sum_{i=1}^{n} \gamma_{it} = 0. \tag{6}$$

The cost function contains a large number of parameters which may result in the lack of degrees of freedom when being estimated alone. Let X_i be the i-th cost minimizing demand input. Using Shephard's Lemma, the i-th input share in total cost C, S_i , or cost share function, is derived as:

$$\begin{aligned} S_i &= \frac{P_i X_i}{C} = \frac{\partial C / \partial P_i}{C / P_i} = \frac{\partial \ln C}{\partial \ln P_i} \\ &= \alpha_i + \sum_{i,j=1}^{n} \gamma_{ij} \ln P_j + \gamma_{iy} \ln Y + \gamma_{it} \ln T. \end{aligned} \tag{7}$$

The cost function (5) and the cost share equations (7) form a system of equations to be jointly estimated with the symmetry and adding-up restrictions imposed across the equations. The system is completed by inclusion of a set of stochastic disturbances to each equation. The estimation efficiency is improved by the inclusion of the cost share equations which provide more information without adding new parameters to be estimated. Since the sum of cost shares is one, the errors from these equations add up to zero and they are not independent. One share equation must be removed from the system to avoid singularity. The system of simultaneous equations with linear restrictions is estimated by the Zellner's iterative procedure, also known as the seemingly unrelated regression (SUR) procedure, in order to deal with the correlation between the disturbances. SUR also ensures that the estimated results are not affected by the choice of the share equation to be dropped from the system.

The estimation of the system requires data on total cost, output, input prices and input cost shares, for each year. Data used for this study are input price and quantity indexes and output quantity indexes calculated in previous studies--see Fantino and Veeman (1994) and Veeman and Fantino (1994a) which also contain additional details on variable construction and data sources. The Tornqvist-Theil index, a discrete approximation to the continuous Divisia index, is used in aggregation. The aggregate output index was constructed from fourteen major crops and five livestock items. The inputs are aggregated into five categories: land and buildings (LND), machinery (MCH), labour (LB), chemicals (CHM), and non-chemical materials (NCM). In the first two categories, stocks are deflated by the corresponding prices or price indexes. Labour is measured on the basis of estimated labour hours in agriculture. Chemicals is an index of fertilizer and pesticides, each measured as farmers' expenditures divided by the appropriate price index. Similarly, non-chemical materials is the aggregate of fuel, electricity, feeds and seeds. All the inputs are constructed following the definitions in Fantino and Veeman (1994), except for the machinery input which is defined as the sum of depreciation and opportunity cost, the latter imputed as 4 percent of the annual nominal value of the machinery stock. Cost shares and price indexes for the five input categories were calculated and are depicted in Figures 1 and 2, respectively, in the preceding section.

III.2 Empirical Results

The system of the translog cost function and four cost share equations with restrictions across equations is estimated for the period 1948-1991. The estimated coefficients of the translog cost function and their asymptotic t-ratios are presented in Table 2.[10] Terms corresponding to γ_{yy}, γ_{tt}, and γ_{ty} were deleted from the original specification of the translog cost function since the estimated coefficients turned out to be not significantly different from zero. The data fit the model well in the sense that R^2, the goodness of fit, is 0.995 for the translog cost function, and 0.882, 0.955, 0.742, and 0.995 for the cost shares of land, machinery, labour , and chemicals, respectively.

Allen partial elasticities of substitution (σ_{ij}) and own price elasticities of demand inputs (η_{ii}) are also derived from this estimation. An Allen partial elasticity of substitution measures how the ratio of a pair of demand inputs responds to a change in the input price ratio, and price elasticity measures the percentage change in quantity demanded of an input for a given percentage change in its price.[11] For the translog cost function, σ_{ij} and η_{ii} have been derived in Binswanger (1974) as:

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[10] The coefficients for the cost share equations can be obtained from the coefficients in Table 1 and the symmetry and homogeneity restrictions.

[11] The relationship between the two inputs is defined as substitutes if raising the price of one factor increases the relative demand for the other. This is specified by $\sigma_{ij} > 0$. Otherwise, if raising the price of one input results in a less relative demand for another, or $\sigma_{ij} < 0$, they are complements. Derived demands are elastic if $\eta_{ii} < -1$; demands are inelastic if $-1 < \eta_{ii} < 0$.

Table 2. Estimated Cost Function, Prairie Agriculture, 1948-1991

Parameter[1]	Coefficient	t-value[2]	Parameter	Coefficient	t-value
α_0	7.261	217.57*	γ_{35}	0.014	0.60
α_1	0.068	22.69*	γ_{44}	-0.062	-2.80*
α_2	0.078	9.92*	γ_{45}	-0.012	-0.50
α_3	0.659	39.84*	γ_{55}	0.130	3.66*
α_4	0.003	0.23	γ_{1y}	-0.012	-2.45*
α_5	0.192	13.97*	γ_{2y}	0.040	3.08*
γ_{11}	0.138	51.61*	γ_{3y}	-0.065	-2.53*
γ_{12}	0.007	1.66**	γ_{4y}	0.108	4.69*
γ_{13}	-0.113	-18.21*	γ_{5y}	-0.071	-3.32*
γ_{14}	0.009	1.70**	γ_{1t}	0.002	1.07
γ_{15}	-0.040	-6.03*	γ_{2t}	0.009	1.99**
γ_{22}	0.048	3.76*	γ_{3t}	-0.049	-5.81*
γ_{23}	-0.015	-0.97	γ_{4t}	-0.007	-0.92
γ_{24}	0.053	3.80*	γ_{5t}	0.045	5.24*
γ_{25}	-0.092	-5.46*	α_y	0.301	6.01*
γ_{33}	0.103	2.98*	α_t	-0.083	-4.77*
γ_{34}	0.012	0.55			

Notes:

[1] Coefficient definitions: 1: land, 2: machinery, 3: labour, 4: chemical, 5: non-chemical.

[2] Asymptotic t-values significant at 1% level and 5 % level are denoted as * and ** respectively.

$$\sigma_{ij}=\frac{\gamma_{ij}+S_iS_j}{S_iS_j},\ i\neq j,\ i,\ j=1,\cdots,\ n. \qquad \eta_{ii}=\frac{\gamma_{ii}+S_i^2}{S_i}-1,\ i=1,\cdots,\ n. \tag{8}$$

here γ_{ij}'s and S_i's are the estimated coefficients of the translog cost function and the cost-shares, respectively. These elasticities are calculated at the mean value of the cost shares of the period under consideration. Results for various time periods are presented in Table 3 and Table 4. These results contain useful information and provide a description of the structure of the agricultural technology. Substitutability relationships are found between the following input pairs: land--machinery, land--chemicals, machinery--labour, machinery--chemicals, and labour--non-chemical materials. Complementarity relationships are present between the land--labour and machinery--non-chemical pairs. The substitutability relation between labour--chemicals input pair, and the complementarity between the land--non-chemical and chemical--non-chemical pairs, are not statistically significant.

Land-chemical and machinery-labour relations in particular have a clear correlate with cultural and production practices. Land and labour have substitutability relationships with every other input, except that they are complements with each other. The results of treating chemicals and non-chemical materials as two individual inputs are worth noting. Initially, we combined these two materials as one intermediate input and found no significant relationships for the pairs of land--material and machinery--material. This may be due to the fact that the chemicals input is a substitute with land and machinery while non-chemical materials is a complement with each of these two inputs. Therefore, it seems appropriate to separate these two intermediate inputs since they associate with other input variables in different ways.

The elasticities in Table 3 exhibit a clear declining tendency in absolute value for all pairs of inputs save the chemicals--non-chemical pair. This tendency represents a reduction in the substitution/complement relationships--in other words, an increased rigidity of the technology over time. In the case of substitutes such as land and chemicals, this means reduced possibilities of substitution. In order to explore this tendency further, elasticities of substitution are calculated annually. The results are depicted in Figure 14. The substitutability between land--machinery, land--chemicals and machinery--labour evidence declining trends for the period 1948-1980, as also do the complementary relationships. The results are consistent with findings in previous studies--see for example Adamowicz (1986) and Rahuma (1989). Our results, however, suggest the tendency has been reversed in the 1980s, and that a slowly raising trend in substitutability and complementarity appeared for most input pairs in the mid-1980s.[12] This implies that the agricultural production structure in the prairies is becoming more flexible in the late 1980s and early 1990s. This tendency may be related to changing economic conditions in prairie agriculture which have had the effect of reducing the use of some inputs, notably fertilizers, pesticides, and

[12] An exception to this is the machinery--non-chemical complementary relationship which does not reveal a clear trend in the period.

Table 3. Allen Partial Elasticities of Substitution, Prairie Agriculture, Selected Periods

Input Pair[1]	1948-1991	1950-1959	1960-1969	1970-1979	1980-1991
LND-MCH	1.291	1.654	1.334	1.238	1.168
t-value[2]	7.380	4.207	6.642	8.649	11.586
LND-LB	-0.780	-1.522	-0.844	-0.664	-0.821
t-value	-7.979	-10.987	-8.332	-7.262	-8.207
LND-CHM	2.136	12.168	3.185	1.948	1.374
t-value	3.193	1.850	2.475	3.490	6.233
LND-NCM	-0.274	-1.055	-0.361	-0.084	-0.050
t-value	-1.297	-3.096	-1.599	-0.468	-0.287
MCH-LB	0.771	0.776	0.781	0.761	0.732
t-value	3.261	3.354	3.460	3.092	2.652
MCH-CHM	7.258	43.493	12.100	6.818	3.356
t-value	4.406	3.888	4.141	4.451	5.411
MCH-NCM	-1.730	-2.042	-1.690	-1.589	-1.570
t-value	-3.458	-3.664	-3.428	-3.350	-3.334
LB-CHM	1.508	3.176	1.813	1.540	1.340
t-value	1.621	0.797	1.218	1.558	2.154
LB-NCM	1.155	1.109	1.137	1.167	1.258
t-value	4.482	6.126	4.968	4.184	2.923
CHM-NCM	-0.043	-4.086	-0.722	-0.009	0.438
t-value	-0.021	-0.400	-0.209	-0.004	0.388

Notes:

[1] LND: land, MCH: machinery, LB: labour, CHM: chemical, NCM: non-chemical.

[2] The standard errors of Allen partial elasticities of substitution are calculated asymptotically by $SE(\sigma_{ij})=SE(\gamma_{ij})/(s_i s_j)$, and are evaluated at the mean values of cost shares in each period.

Figure 14: Allen Partial Elasticities for Some Input Pairs

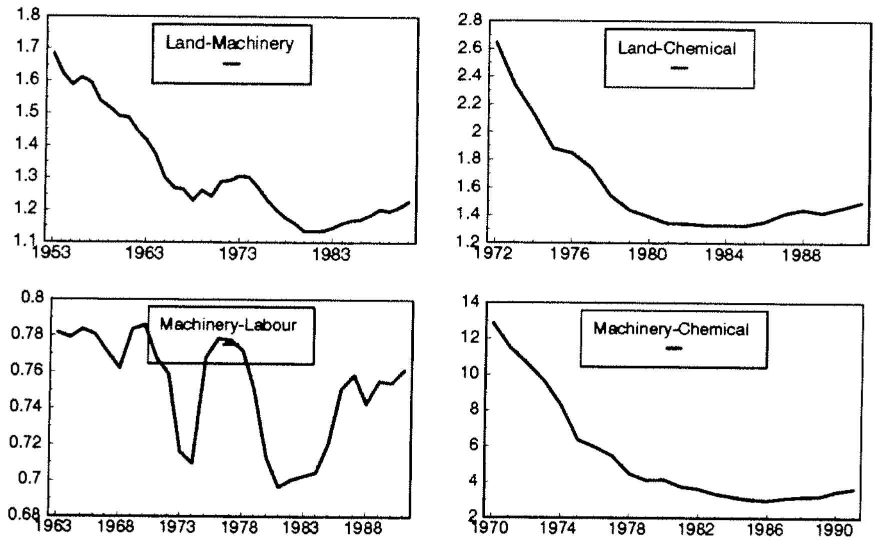

Table 4. Elasticities of Input Derived Demands, Prairie Agriculture, Selected Periods

Input	1948-1991	1948-1960	1961-1970	1971-1980	1981-1991
Land	0.072	0.746	0.163	-0.035	-0.135
t-value[1]	4.008	23.162	8.174	-2.315	-10.616
Machinery	-0.541	-0.498	-0.537	-0.547	-0.561
t-value	-6.761	-4.999	-6.519	-7.158	-8.640
Labour	-0.332	-0.268	-0.316	-0.345	-0.355
t-value	-4.084	-4.191	-4.193	-3.896	-3.037
Chemicals	-2.104	-7.299	-2.964	-2.072	-1.422
t-value	-5.095	-3.243	-4.164	-5.154	-7.419
Nonchemical	-0.174	-0.214	-0.191	-0.177	-0.105
t-value	-1.036	-1.423	-1.186	-1.060	-1.060

Notes:

[1] The standard errors of own price elasticities of demand inputs are calculated asymptotically by $SE(\eta_{ii})=SE(\gamma_{ii})/s_i$.

machinery, increasing somewhat the degree of input substitution, and leading to a slightly more flexible agricultural system.

Estimated derived (own) price elasticities of input demand in various periods are listed in Table 4. Demands for machinery, labour and non-chemical materials are all inelastic with respect to changes in their respective prices, with demand for non-chemical input being the most inelastic one. These results appear reasonable for the inputs in question. The highly inelastic derived demand for non-chemical materials indicates farmers have little possibilities of substituting for current use of energy, feed, and seeds. Given our specification, we only are able to report elasticity of demand for the aggregate. Both the machinery and labour inputs exhibit slightly increasing degrees of responses to their price changes over time. On the other hand, chemical materials are demand elastic, but the degree of sensitivity to price changes exhibits a decreasing trend. Elasticities of derived demand for land exhibit contradictory signs for some periods. The positive response of demand for land to its own price may be explained as the consequences of the escalated land prices in certain periods, notably from the early 1960s to the early 1980s, and the large capital gains farmers were expecting from land.

III.3 The Structure of Production Technology and Hypothesis Testing

As stated earlier, the translog specification for the agricultural cost function is a flexible, less restrictive specification of the underlying technology of production. Additional justification for its use in this study is obtained by statistical tests. In this section, some important properties of properties to be tested include: (1) homotheticity; (2) constant return to scale; and (3) Hicks neutral technical change.

The first, homotheticity, refers to the shape of isoquant curves and it can be expressed as the property that the cost share functions are independent of output[13], or that $\gamma_{iy}=0, i=1,...,5$. If the joint hypothesis H_0: $\gamma_{iy}=0, i=1,...,5$ is rejected, the production structure is non-homothetic. A variation in output level will affect not only input demand, but also input cost shares.[14] Constant returns to scale, a special case of the homothetic functional form, occurs if a proportional change in all inputs results in a change of output of the same magnitude. The translog cost function exhibits constant return to scale when the following holds: $\alpha_y=1$, $\gamma_{iy}=0, i=1,...,5$. This can be statistically tested; if the null hypothesis is rejected, scale economies exist. Finally, technical change occurs when the amount of output increases with the level of inputs unchanged, and it is characterized by an inward shift of the isoquant curves. In the special case when the isoquants

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[13] Homotheticity implies that with input prices unchanged, changing output level affects the demand of inputs in a way that their factor cost shares remain the same, and output is separable from input prices in a cost function.

[14] In addition, If an expansion in output results in an increased proportion of the i-th factor demand in total cost, i.e. $\gamma_{iy}>0$, it is called *i*-th factor non-homothetically using. Otherwise, if $\gamma_{iy}<0$, it is *i*-th factor non-homothetically saving.

shift homothetically, technical change is defined as Hicks neutral. In a cost function with Hicks neutral technical change, the level of technology, represented by T, is separable from output quantity and input prices. In a translog cost function, this implies that changing T does not affect the factor shares, and corresponds to the following null hypothesis: $\gamma_{it}=0$. If the null hypothesis is rejected, the technology is defined as biased.[15] The likelihood ratio test method is utilized for testing the hypotheses specified above. [16]

Test results indicate that the null hypotheses of homotheticity, constant return to scale and Hicks neutral technical change are all rejected at the one percent level of statistical significance. This strongly suggests that the agricultural production structure of the prairies is profiled by non-homotheticity, Hicks biased technical change, and scale economies. Furthermore, the estimated coefficients γ_{iy} in Table 1 indicate that non-homotheticity is characterized as machinery and chemicals using, and land, labour and non-chemical materials saving. The Hicks biases in technical change, as inferred from the signs of the estimated $\gamma_{it,}$ are: machinery and non-chemical materials using, labour saving, while land and chemicals are Hicks neutral. These results clearly suggest that the labour saving and machinery using features of prairie agricultural technology result from both non-homotheticity and biased technical change. The non-homothetic land saving property of the technology may result from the slow growth in land supply, limited by availability of suitable land to be developed and the capital investment needed for such development. Land price scalation during the inflationary 1970s and 1980s may also be related to this. Our empirical results also suggest that chemicals, composed of fertilizers and pesticides, are quantitatively used to increase output although technical efficiency may not have improved significantly.[17] On the other hand, our results suggest the opposite for non-chemical materials. These intermediate inputs, chiefly composed of feeds, seeds and energy inputs, seem to have been used with increased efficiency in the period .[18]

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[15] In this case, technical change reduces the total cost by varying the amount of inputs used for production as well as their cost shares. If a technical change increases the share of i-th factor demand, characterized by $\gamma_{it}>0$, it is called i-th factor Hicks using. Otherwise, if $\gamma_{it}<0$, it is i-th factor Hicks saving.

[16] The test statistic follows a $\chi^2(q)$ distribution, and the number of degrees of freedom is determined by the number of restrictions in the hypothesis.

[17] Similar results were obtained using a different methodology in a previous study on the productivity of chemicals in prairie agriculture--see Veeman and Fantino(1994b). Both fertilizers and pesticides, the bulk of which are inputs in the crop sector, have experienced since the 1950s pronounced downward trends in partial productivities (Section III, pages 12-16). It is to be noted that fertilizers and pesticides are in a complex relationship at the production level which includes interaction effects with weather--see Veeman and Fantino (1994b) and (1990).

[18] This would be consistent with increased efforts to use energy efficiently and production improvements in the use of feeds coupled with better seed quality over the period. Besides, these

III.4 Some Conclusions

A translog cost function was estimated for prairie agriculture over the period 1948-1991. Cost function parameters, elasticities of derived demand for inputs, and Allen elasticities of input substitution are calculated in this paper. The results indicate an increasingly rigid production structure in the 1970s and early 1980s, in agreement with previous estimates. The agricultural production technology exhibits trends toward lower elasticities of derived input demand and reduced input substitution. Such trends suggest that technology in prairie farming was becoming a "technological package", that is to say, a technology characterized by a more or less fixed input bundle. The predominance of inelastic factor demands, with the exception of chemicals, implies that the possibilities of altering the structure of production by prices alone is not present. The trend to increasing rigidity was modestly reversed in the late 1980s when a slowly changing input mix resulted from reduced use of chemicals and machinery. These changes may be related to changing economic conditions which generally favoured cost reduction as opposed to output expansion as in the previous period. The relatively slow response of the system, however, indicates the persistence of rigidities and narrow input choices for farmers. Further analysis of the structure of the underlying technology centred on statistically testing functional properties of the cost function. Test results indicate rejection of homotheticity, of constant return to scale, and of Hicks neutrality.

Finally, some concluding comments, including limitations and policy implications, are in order. Limitations of the study include the degree and nature of output and input aggregation. Further disaggregation of certain inputs, such as chemicals into fertilizer and pesticides and of capital items, would be of interest. Data limitations and econometric problems are constraints in this respect. In terms of results, the findings concerning non-homotheticity, the biases in technological change, and the presence of scale economies are an indication of the complex structure of technology in prairie agriculture. Further research in this area is certainly of interest and is currently being carried out by the authors. The findings concerning the existence of inelasticites and rigidities in the farming system is of course not a big surprise or entirely new. Agriculture has historically been moving in that direction for decades. What is interesting, however, is the recent modest reversal of these tendencies. It is not yet clear whether the increased flexibility which has occurred in prairie agriculture in the late 1980s is the start of a new trend or a temporary reversal in the historical trend towards greater rigidity.

Although the structure of production technology is only one factor in the profitability/competitiveness/sustainability equation facing farmers, it nevertheless constitutes an important factor in policy design for the agricultural sector. One important area that potentially may have an impact on the characteristics of agricultural technology relates to agricultural research and development(AR&D). By the introduction of innovations, such as genetic improvements and new varieties or cultural practices, the set of agricultural technological choices may be expanded with increased availability of input substitutes for farmers which in

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inputs do not seem to stimulate output growth appreciably through the amount used.

turn may make the production structure more flexible or at least less inflexible than it otherwise would be. Although in the long run the production system tends to adjust (via induced innovation), rigidities in the short run may last a number of years, hence the importance of AR&D policy formulation. The most important factor in a successful R&D strategy, besides the quantity and quality of resources involved, is to focus the research agenda on important and relevant objectives. Econometric study of basic features of the structure of production improves our understanding of the issues involved which in turn may assist in the definition of such relevant objectives.

IV. Capital, Technical Change, and Agricultural Productivity[19]

In this Section, the appropriate choice of index numbers in aggregating outputs and inputs, which must underlie the measurement of productivity, is emphasized. In particular, the use of traditional, fixed base weight, indexing procedures, such as the Laspeyres and Paasche, is compared and contrasted to the use of improved flexible index number approaches such as the Tornqvist-Theil approximation to the Divisia index and the Fisher index. More refined and up-to-date estimates of aggregate output, input, and productivity, based on the Tornqvist-Theil approach, are presented for Canadian agriculture and the prairie agricultural sector of western Canada. A more detailed comparison of the alternative index number approaches is then undertaken emphasizing western Canada as a case study. Finally, recommendations are drawn with respect to the relative merits of these alternative index number procedures in measuring productivity and in making productivity comparisons.

The measurement and assessment of agricultural productivity is essential not only to a better understanding of agricultural growth but also to the issues of longer run competitiveness and economic sustainability. Comparisons of productivity over time are obviously important in assessing whether trends in the technical efficiency of production are increasing or decreasing. Productivity comparisons across regions, industries, and nations are also critical to policy-makers. However, such comparisons, to be relevant, require more understanding and agreement on how productivity is to be measured.

IV.1 Conceptual Issues in Measuring Productivity

Much productivity discussion is based on partial productivity measures such as yield per acre (land productivity) or output per person (labour productivity). Such partial productivity measures can be seriously misleading if considerable input substitution is occurring in production. A conceptually superior way to estimate productivity is to measure total factor productivity (TFP)--the ratio of aggregate output (Y) over the aggregate of all inputs (X) used in agricultural production. That is the focus of this section. There are two basic economic

[19] The initial part of this section is based on Fantino and Veeman (1994): "The Choice of Index Numbers in Measuring Productivity: A Canadian Empirical Case Study.", paper presented at the XXII International Conference of Agricultural Economists held in Harare in August 1994.

approaches to the measurement of productivity or technical change: the growth accounting or index number approach and the econometric approach in which the shift of the production or cost function is measured (Antle and Capalbo 1988, pp. 48-63). The productivity work reported in this paper is based on the first approach--the index number approach.

Among the most important and most difficult issues in measuring productivity by the index number route is the choice of an appropriate index number methodology to combine several agricultural outputs into an aggregate output index or to combine several farm inputs, suitably weighted, into an aggregate input index. Economists have shown that there is an exact correspondence between a given indexing procedure and the specific functional form of the aggregate production function which that index number procedure implies. We concentrate in this paper on the choice between traditional approaches such as the Laspeyres index or the Paasche index and flexible index procedures such as Divisia-related or Fisher indexes.[20] Most published works on agricultural productivity in Canada, particularly that done under the aegis of Agriculture Canada, has involved Laspeyres index number methods--for example, Brinkman and Prentice (1983) and Nayaranan and Kizito (1992). Such indexing procedures, wherein base period prices are used as weights in aggregation, imply that the underlying production function is linear and that inputs in the production process are perfect substitutes.

Because of the restrictive nature of the production technology associated with the linear and Cobb-Douglas production functions, attention shifted in the 1970s to flexible form production and cost functions. A functional form or aggregator is called flexible if it is a second order approximation to an arbitrary twice differentiable homogeneous function. An indexing procedure which corresponds to a flexible aggregator is also flexible, or superlative in Diewert's (1976) terminology.

The flexible indexing procedure employed during the past two decades in productivity analysis has been Divisia-related. The continuous Divisia index has properties which make it advantageous in aggregation (Hulten 1973). Moreover, the Tornqvist-Theil index, a discrete approximation to the Divisia index, was shown to be a superlative index and exact for a homogeneous translog production function (Christensen 1975, Diewert 1976). In this flexible production technology, the elasticity of substitution between any input pair is flexible and inputs can be either substitutes or complements. In Tornqvist-Theil indexing, input cost shares (to be more specific, the arithmetic average of the input cost share in period t and the corresponding input cost share in period t-1) are used to weight respective input quantities in year t in constructing an aggregate input index. Analogously, output value shares, which are also flexible over time, are used to derive the Tornqvist-Theil aggregate output index. The practical cost of these conceptual improvements in indexing is that more data are required: price and quantity data are needed for each input and each output for every year in the time series period under

[20] Another option, not discussed here, is geometric aggregation, following Solow, in which factor shares are used to construct an aggregate input index, and in which Cobb-production technology is implied.

examination.

The Fisher "ideal" index, defined as the geometric mean of the Laspeyres and Paasche indexes, is also superlative, and corresponds to a quadratic mean of order two production function (Diewert 1976). The Fisher index and its chained variant have not been employed in much empirical work on productivity. However, Fisher indexing enjoys certain interesting properties which induced us to include it in our study. These properties arise from the so called "axiomatic approach" to index number construction. In this approach, desirable properties of indexing are defined, and the different indexing procedures are examined in this respect. The Fisher index is the only index that satisfies twenty relevant properties (Diewert 1989b). The Tornqvist-Theil index, for example, fails the constant quantity test while the Laspeyres and Paasche indexes fail in regard to important properties, such as the time or region reversal tests (Diewert (1989a). Recently, Bureau et al (1994) use a Fisher based index for the purpose of international productivity comparisons.

Finally, there is the issue of defining the base in the indexing procedure. Laspeyres, Paasche and Fisher are fixed base procedures, the comparison year being fixed. The Tornqvist-Theil index involves a chaining procedure where the weights adjust every year in terms of the data for the current year and the previous year. A chaining procedure can also be applied to the Laspeyres, Paasche, and Fisher indexes to obtain "chained" versions of each. There appear to be no clear theoretical reasons to prefer the chained index over the unchained, although intuitively the chaining appears to be preferable. In our empirical study all seven indexes are used.

IV.2 Estimation and Data

In using the index number approach to estimate productivity, total factor productivity (TFP) is derived as the ratio of aggregate output over aggregate input use. TFP growth in this framework is the residual difference between the rate of growth of aggregate output and the rate of growth of aggregate input. The first step is estimating productivity, therefore, is constructing indexes of aggregate output and aggregate input. To this end, data on production and average prices paid to farmers, as well as on input quantities or annual expenditures on input items by farmers, were collected for each year between 1948 and 1991. Data were obtained from several published and unpublished sources, the main sources being Statistics Canada and Agriculture Canada.

An aggregate output index comprising both crops and livestock was constructed for Canada and for the prairie region, comprising the provinces of Alberta, Saskatchewan, and Manitoba. Fourteen major crops were included: wheat, oats, barley, rye, mixed grain, corn, flax, soybeans, mustard, potatoes, hay, rapeseed, sunflower, and sugar beets. The livestock items included were: cattle and calves, sheep and lambs, pigs, chicken, turkeys, eggs, and dairy. The input side of the productivity equation included the input categories of capital, labour, and intermediate inputs or materials. More specifically, the aggregate input index included: land and buildings, summerfallow, machinery and livestock capital; labour comprising hired workers, unpaid farm operators, and family workers; and material items including fertilizer, pesticides, fuel and oil, electricity, seeds, animal feeds, and irrigation.

The construction of the index for aggregate inputs involves many conceptual and empirical problems. The major difficulty is that several "durable" inputs, such as land and machinery, are used in production. The best measure of input use is represented by the service flows provided by the stocks, rather than the stocks themselves. Furthermore, not all input use involves actual cash outlay for the farmer so imputation is needed in the case of inputs such as land or unpaid operator and family labour. The annual service flows of the land, buildings, and livestock capital items were assumed to be opportunity costs imputed as 4 percent of the respective nominal values. For machinery, depreciation and repairs were considered to be the relevant service flow and no opportunity cost was included. The labour input was derived in terms of man-hours data, although this required extrapolation for early years in the time period prior to 1966. For inputs with an imputed service flow or an actual annual expenditure (such as most material items), an implicit quantity index was computed by dividing the value of the service flow or expenditure by an appropriate price index.

Initially, the index number procedure used to derive aggregate output and aggregate input for Canada and for the prairie region of western Canada was the Tornqvist-Theil approximation to the Divisia index. The resulting output, input, and TFP indexes for agriculture in Canada are graphically portrayed in Figure 15. The same indexes for western Canada, also Divisia-based, are shown in Figure 16. Using the western Canadian data set, six further indexing procedures were implemented to measure aggregate output, input, and TFP in the prairie region: Laspeyres, Paasche, Fisher, Laspeyres Chained, Paasche Chained, and Fisher Chained. The resulting productivity index numbers are plotted in Figures 17 and 18 and compared with the Divisia-based estimates of productivity.

IV.3 Empirical Results

Levels of agricultural output and productivity more than doubled in Canada (Figure 15) and the prairie region (Figure 16) between 1948 and 1991. Input use in Canadian agriculture actually declined over the entire period, led by sharp declines in labour employed in the 1950s as capital was substituted for labour. The time path of the productivity index closely follows that of the output index in both Canada and the prairies although from the mid-1970s on the two curves tend to diverge as output grows faster than productivity.

Estimated compound growth rates of output, input, and productivity for Canadian and prairie agriculture are briefly summarized in Table 5. These estimates are based on the Tornqvist-Theil approximation to the Divisia index. Canadian agricultural output, for example, grew by 1.86 percent per year over the entire period from 1948 to 1991, aggregate input use declined marginally by -0.02 percent per year, and productivity (TFP) increased by 1.88 percent per

Figure 15. Indexes of Output, Input and TFP, Canadian Agriculture, 1971=1

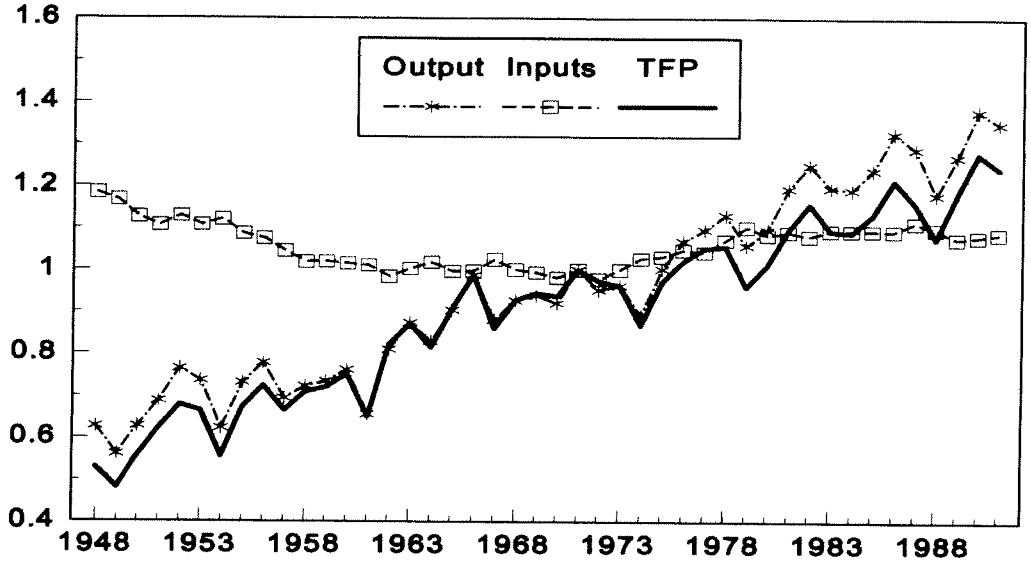


Figure 16. Indexes of Output, Input and TFP, Prairie Agriculture, 1971=1

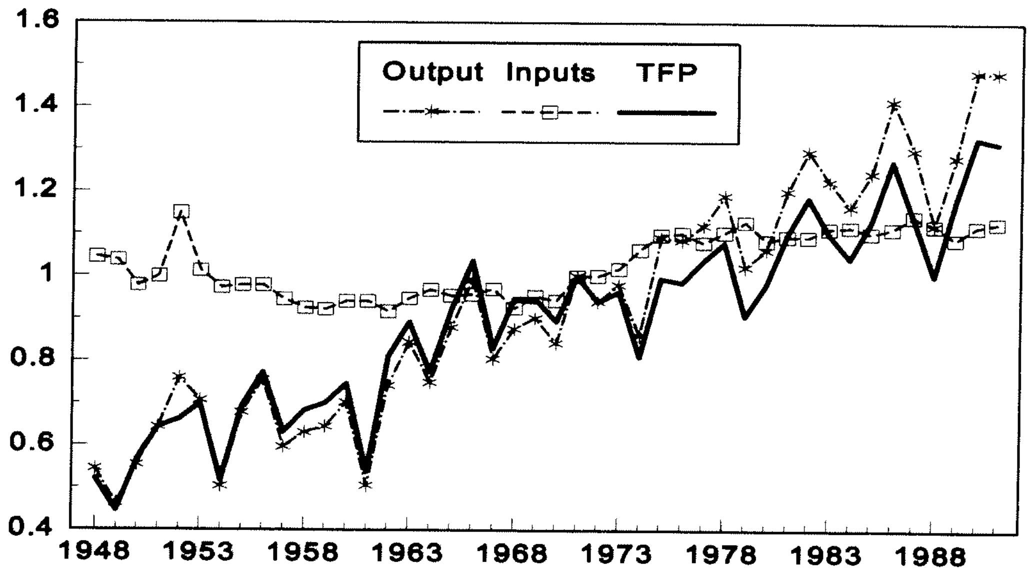


Figure 17. Productivity Indexes, Prairie Agricuture, 1948=1

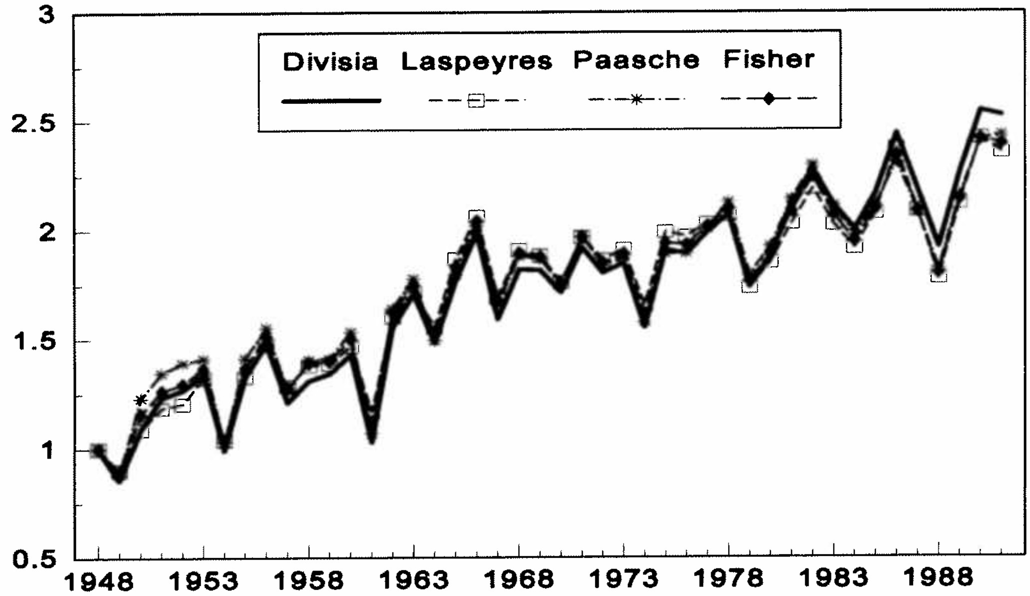
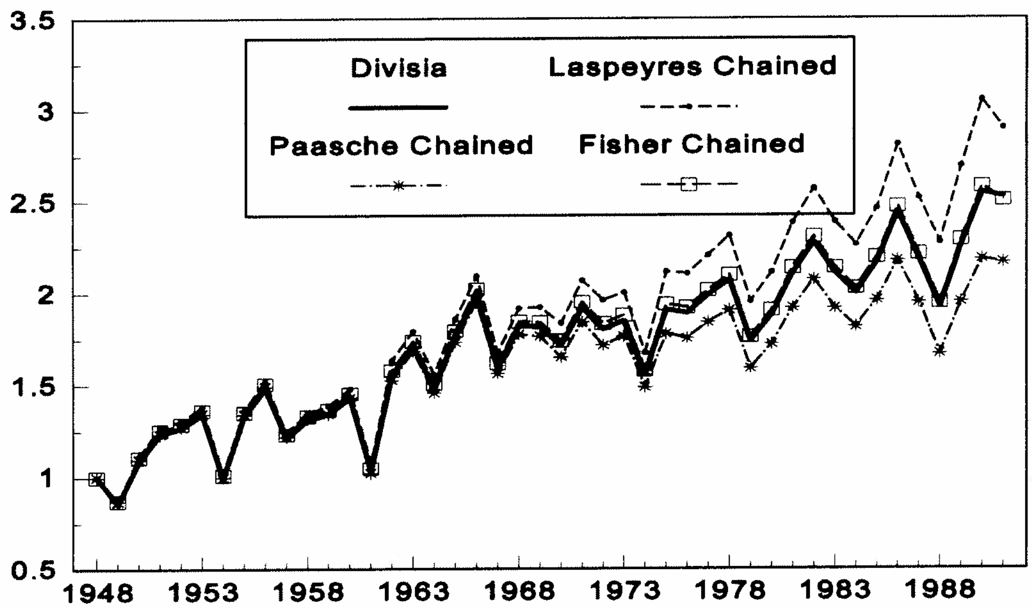


Figure 18. Productivity Indexes, Prairie Agriculture, 1948=1



annum.[21] In prairie agriculture, output increased more rapidly at 2.31 percent per year, input use rose moderately at 0.38 percent per year, and productivity increased at 1.92 percent per year between 1948 and 1991. Most output growth, therefore, was due to productivity growth rather than increased use of inputs. Since 1962, output and productivity have grown somewhat less rapidly in both Canada and the prairie region. Estimated rates are highly sensitive to the particular time period chosen. Both output and productivity exhibit large yearly variations mainly due to weather conditions. Using a drought year (1961 or 1974) as initial or final year biases growth rate estimation considerably. In previous research (Veeman and Fantino 1990, 1985), about 80 percent of the variation in productivity is explained with a time trend and a number of weather variables. It is also possible to estimate "weather-corrected"growth rates.

Table 5. Annual Growth Rates in Canadian and Prairie Agriculture, Divisia-Based, in Percent, Various Periods

	Output	Input	Productivity
Canada			
1948/1991	1.86	-0.02*	1.88
1962/1991	1.7	0.43	1.27
Prairies			
1948/1991	2.31	0.38	1.92
1962/1991	2.07	0.75	1.32
1978/1991	1.92	0.12	1.79
1980/1991	1.94	0.24	1.7
1982/1991	1.61	0.15*	1.46
1984/1991	2.56	0.06*	2.5

*Non-significant at the 10% level of confidence

The rates in Table 5 indicate a strong growth in both output and productivity over the whole period and in the 1980s. On the other hand, the index of input used in agriculture has

[21] This productivity growth estimate for Canadian agriculture is quite similar to those calculated for agriculture in the United States over relatively similar time periods--for example, Ball's estimate of 1.83 percent for year over 1948-89 and Jorgenson and Gollop's estimate (1992) of 1.58 percent over 1947-85.

experience a downward trend over the first half of the period and an upwards trend in the second which continues, although at a reduced rate, into the 1980s. The result is that the input index exhibits practically no change over the whole period 1948-1991. It is important to note the growth trends in the 1980s, the period where the large drop in investment is recorded. Growth rates are very sensitive to the particular time period chosen for comparison. This is due to the large variations that both output and productivity experience year by year, variations that are mostly due to weather and environmental factors. Even so, it is clear that agricultural production has continued to grow after the mid 1980s which suggests that no appreciable reduction in productive capacity has occurred. Productivity growth in that period also points to the same conclusion. Besides, crop livestock output figures in the early 1990s suggest further relatively strong output growth.[22] The large drop in capital investment observed in Section II does not appear to have had any appreciable effect on productive capacity at least up to the early 1990s.

IV.4 The Choice of Index Numbers in Measuring Productivity

The choice of a particular index number procedure is important to the magnitude of estimated growth rates. In Table 6, growth rates of output, input, and productivity in agriculture in the prairie region of western Canada over various time periods are presented for seven different index number procedures. In the right hand side of Table 6, these respective growth rates are indexed relative to the Divisia-based estimates. A relatively large discrepancy is evident between growth rates estimated from Divisia (Tornqvist-Theil) indexes and those estimated from Laspeyres or Paasche indexes. For example, over shorter time spans such as 1971 to 1991, the Laspeyres based estimate of productivity growth is 40 percent below the Divisia-based estimate. A notable feature of these empirical results is that growth rates obtained from Divisia-based indexes are very similar to those generated from the Fisher chained index. In Figure 17, it is apparent that the productivity time paths for the Divisia-based (Tornqvist-Theil) index and the chained Fisher index are nearly the same.

Productivity growth rates under the seven alternative indexing procedures were also calculated for Canadian agriculture (not reported here), with generally similar results occurring, particularly for longer time periods. The Tornqvist-Theil and chained Fisher based rates of productivity growth diverge somewhat more than in the case of the prairies, a more agriculturally homogeneous region, but are still well within ten percent of each other.

IV.5 Productivity and Profitability: Terms of Trade and the Returns-Cost Ratio

The index number methodology used in this section to estimate productivity is also

[22] The Statistical Handbook 1994 published by the Canada Grains Council indicates record levels of production for wheat in 1990 and 1991 for Manitoba, Alberta, and Saskatchewan respectively. Similarly, 1994 is a record year for canola production in the prairie provinces. Estimated total farm production of livestock in 1992 and 1993 is above the average production level in the period 1983-1992.

Table 6. Output, Input, and Productivity Growth Rates, Prairie Agriculture, Various Index Procedures

	In Percent per year			Relative to Divisia		
	Output	Input	TFP	Output	Input	TFP
1948-1991:						
Divisia	2.31	0.38	1.92	1.00	1.00	1.00
Laspeyres	2.13	0.37	1.75	0.92	0.99	0.91
Paasche	2.16	0.49	1.66	0.93	1.29	0.86
Fisher	2.14	0.43	1.71	0.93	1.14	0.89
Laspeyres Chained	2.73	0.42	2.30	1.18	1.12	1.19
Paasche Chained	1.88	0.34	1.53	0.81	0.90	0.80
Fisher Chained	2.30	0.38	1.91	1.00	1.01	0.99
1962-1991:						
Divisia	2.07	0.75	1.32	1.00	1.00	1.00
Laspeyres	1.77	0.88	0.88	0.86	1.18	0.67
Paasche	1.82	0.79	1.02	0.88	1.05	0.78
Fisher	1.80	0.84	0.95	0.87	1.11	0.72
Laspeyres Chained	2.58	0.80	1.77	1.24	1.06	1.34
Paasche Chained	1.54	0.71	0.82	0.74	0.95	0.62
Fisher Chained	2.06	0.75	1.29	0.99	1.01	0.98
1971-1991:						
Divisia	2.01	0.45	1.55	1.00	1.00	1.00
Laspeyres	1.59	0.66	0.92	0.79	1.45	0.60
Paasche	1.62	0.47	1.15	0.81	1.04	0.74
Fisher	1.61	0.56	1.04	0.80	1.25	0.67
Laspeyres Chained	2.51	0.49	2.01	1.25	1.09	1.29
Paasche Chained	1.43	0.42	1.01	0.71	0.93	0.65
Fisher Chained	1.97	0.46	1.51	0.98	1.01	0.97

Source: Fantino and Veeman (1994), page 10.

useful to obtain estimations of changes in profitability over time. Index numbers may be constructed in a similar fashion for prices. In this case quantities are used as weights and the same procedures detailed previously can be applied. Index numbers for aggregates of output prices and input prices are calculated in this fashion. The ratio of the output price index to the input price index is a measure of prices received by farmers relative to prices paid by farmers. We call this ratio an index of the *terms of trade* of the agricultural sector. A measure of profitability, the *returns to cost ratio*, is obtained by the following expression:

Returns to Cost Ratio Index=(Productivity Index) x (Terms of Trade Index)

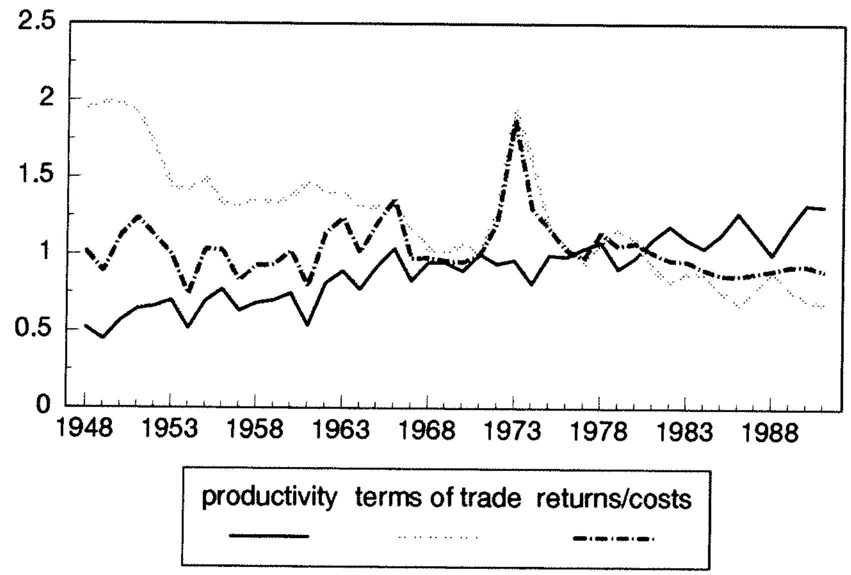
The returns to cost ratio is therefore calculated as the product of the productivity index and the terms of trade index which are directly calculated from the data on prices and quantities of outputs and inputs in agriculture. As its name indicates, the returns to cost ratio is an index of the value of output relative to the value of the inputs involved[23]. As with any index of profitability, it should be regarded as relative measure of profitability only, that is to say, it represents profitability in any year relative to the base year. Changes in profitability over time are nevertheless measured by the returns to cost index. Figure 19 plots the calculated indexes for the prairies and Table 7 presents estimated growth rates.

Table 7. Productivity, Terms of Trade, and Returns to Cost Ratio, Prairie Agriculture, Annual Growth Rates in Percent

	1948\1991	1980\1991
Productivity	1.92	1.70
Terms of Trade	-2.02	-2.85
Returns to Cost Ratio	-0.14*	-1.21

[23] This is thus a crude measure of profitability of the whole agricultural sector, related to but not identical with the average rate of profitability. It also should be taken into account that our measure includes, on the cost side, the inputed costs of the capital inputs, land, buildings, machinery, implements and facilities. The difficulties associated to its measure have been already extensively discussed. Machinery costs may be under or over-estimated in different periods. As to land costs, the main problem here is that they are included in the calculations as a fixed proportion of value whereas land should properly be regarded as a residual claimant of output. Again, this may overestimate costs.

Figure 19. Returns to Costs, Terms of Trade and Productivity in Prairie Agriculture, 1971=1



The downward trend in terms of trade is apparent, and accelerates somewhat since the mid 1980s. This is a numeric and graphic expression of the "cost-price squeeze" facing farmers. On the other hand, productivity has been increasing over the period at the considerable rates presented in Table 5. The result of these opposite trends is that the product of the two, the returns to cost index, experienced little variation over the entire period as indicated in Table 7 where the estimated annual growth rate for the whole period is negative but represent a small drop in profitability being statistically not significantly different from zero. In contrast, the rate for 1980-1991 represents more of an impact on profitability and is significant. Productivity improvements are closely related to technological change, including economies of scale, which highlights the importance of the latter for the profitability and competitiveness of the farming sector.[24]

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[24] The economic forces involved are in a complex relationship. Note that profitability depends on the level of prices while agricultural productivity affects the level of output with given inputs. Input price reduction due to technical change in the industries supplying agricultural inputs may lead to price reductions which improve farmers' terms of trade. On the other hand, higher agricultural productivity may increase markets supplies and, if demand does not keep pace, lead to reduced output prices and a deterioration of farmers' terms of trade depending on the relative strength of the supply and demand responses(elasticities). That is the case in the famous agricultural "treadmill" analogy.

IV.6 Economies of Scale, Technical Change and Productivity Growth

In the previous sub-sections, Total Factor Productivity (TFP) has been defined as the ratio of aggregate outputs over aggregate inputs and estimated by means of the index numbers approach. The effects on TFP of capital investments and modern inputs such as agrochemicals and seeds was considered. In our discussion the growth trend of TFP was attributed to technical change broadly interpreted.[25] However, such a broad definition embraces not only pure technical change but also a number of other factors such as economies of scale, movements towards productive efficiency (from technically inferior positions), or possible adjustment in disequilibrium conditions associated with technology (in particular, a higher degree of capacity utilization) . In a more strict sense, we may define technical change as any modification of the underlying production function, that is to say, a shift inwards of the production isoquants. On that basis we have to recognize that it is possible for the TFP index to grow without any shift in the underlying production function. This occurs when improved efficiency is achieved, when economies of scale are present, or a combination of the two. The growth in a productivity index is a catch-all measure which includes things other than pure technical change interpreted in a strict sense. The case of economies of scale is the focus in this sub-section.

In the previous sections TFP growth was measured by the *index numbers approach.* TFP growth can also be measured by a different methodology based on production or cost function estimation and known as the *econometric approach.* In the econometric approach, the growth of TFP is measured by the proportionate shift over time of the production function, which in the absence of changes in productive efficiency, is really pure technical change. On the other hand, TFP growth measured by the index number approach include scale effects and other effects that may be present besides technical change. Capalbo (1988) advocates the estimation of the shift of a cost function to evaluate pure technical change.[26] Since the test of hypotheses conducted in Section III suggests that agricultural productivity growth in the prairies is characterized by scale economies and technical change, we apply Capalbo's methodology to estimate rates of technical change and the effects of economies of scale. The rate of technical change in the cost function

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[25] Note that there are other factors affecting TFP beside technical change, notably weather and environmental factors. Weather is responsible for the relatively large year to year fluctuations around the trend line observed in Figures 15 and 16.

[26] Capalbo makes the point that productive efficiency, the scale of production and the state of technology are all reflected in TFP. She reasonably argues that identifying TFP growth with technical change will be misleading when scale effect are present. In this context, and ignoring efficiency effects, the shift of a cost function is a more adequate estimate of technical change. This is the approach we are following in this section. Nevertheless, it is to be noted that if the effects on output and productivity of the introduction of new, different, inputs in the input mix are regarded as technical change in a proper sense, the estimated growth rates would be biased. These may be some reasons for the unconvincing results Capalbo obtains with the methodology applied to United States agriculture.

framework is the downward proportionate intertemporal shift of the cost function, which is given by the following expression:

$$-\Delta C = -\frac{\partial C}{\partial t}\frac{1}{C} = -\frac{\partial \ln C}{\partial t} \tag{9}$$

The rate of returns to scale (*RTS*) is defined as the proportional increase of all outputs in response to a proportional increase in all inputs. Caves, Christensen and Swanson (1981) derive a formula for calculating *RTS* from a total cost function as follows:

$$RTS = \left(\sum_i \frac{\partial \ln C}{\partial \ln Y_i}\right)^{-1}. \tag{10}$$

In the case of constant returns to scale, *RTS* is unity. Increasing and decreasing returns to scale are represented by $RTS>1$ and $RTS<1$, respectively.

The rates of technical change and returns to scale have been calculated for prairie agriculture by means of Capalbo's methodology. The results are presented in Figure 20. Since *RTS* is greater than one at each point, the response to a one percent increase in all the inputs would be an output increase of a larger percentage. This means that prairie agricultural production is characterized by increasing returns to scale. Also, the degree of returns to scale exhibits an increasing trend over the period, suggesting that technical change has a positive influence on it. The rate of technical change, on the other hand, decreases with time, implying that the influence of technical change estimated on total factor productivity growth has diminished over the period.

Following Capalbo, the growth rate of TFP may be decomposed into factors associated with technical change and non-constant returns to scale, respectively. For prairie agriculture, annual compound growth rates in percentages for output, input and TFP, and the decomposed technical change and scale effects are calculated for the period 1948-1991 and listed in Table 8. The growth rates of technical change and increasing return to scale as percentages of TFP growth are presented. TFP grows at a slower rate in the period 1962-1980, due to the increasing growth of inputs and continuing decline of the output growth rates. But the situation starts to change after 1980, ΔTFP going up due to the reduced use of inputs. For the overall period 1948-1991, TFP growth is 2.1 percent per year, the residual difference between output growth and aggregate input growth. TFP growth is estimated to be due primarily to increasing returns to scale, which accounts for 72% of the growth. Technical change, or the intertemporal shift of cost function, decreases at a annual rate of 0.55%, and is estimated to account for about 26% of productivity growth.

Figure 20. Rates of Returns to Scale (RTS) and Technical Change for Prairie Agriculture

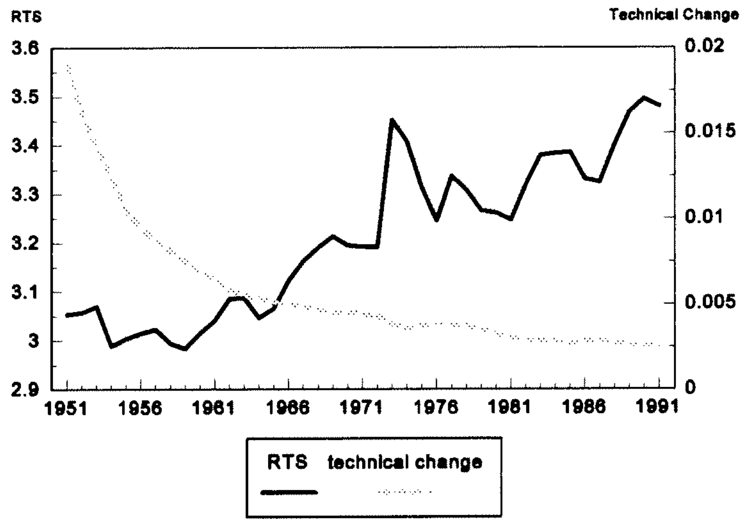

Table 8. Decomposition of TFP Growth Rate

ΔY (1)	ΔX (2)	ΔTFP (3)	-ΔC (4)	ΔRTS (5)	(3)-(4)-(5)
2.217	0.120	2.094	0.547	1.518	0.029
(15.6)	(1.6)	(14.4)	(19.4)	(15.9)	
		100.00%	26.12%	72.49%	1.39%

IV.7 Concluding Comments on Capital, Productivity, and Profitability

In this Section, the choice of index number procedures in the empirical measurement of agricultural productivity has been analyzed. Measures of output, inputs, and total factor productivity vary considerably depending on the index number used in aggregation. Our empirical results for the Canadian prairies suggest there is little practical difference in estimates of productivity growth based on the Tornqvist-Theil approximation to the Divisia index as compared to the Fisher "ideal" chained index. Either of these superlative indexes is to be preferred, for both conceptual and empirical reasons, over the Laspeyres index or its chained variant in the measurement of agricultural productivity.

Calculated output and productivity growth rates indicate continuing growth into the early 1990s. This suggests that any dis-investment that may have taken place in prairie agriculture since the mid 1980s has had no major effect on output and productivity. Estimations by means of a methodology by Capalbo suggests, in agreement with our own statistical tests in the previous section, significant economies of scale in prairie agriculture. Decomposition of growth rates by the same methodology indicates that economies of scale account for a sizable portion of productivity growth.

Terms of Trade and the Returns to Cost Ratio are also estimated. Continuing deterioration of the prairie farming sector's terms of trade seems to have been compensated historically by increases in productivity. As a consequence, and despite large year to year variations, the returns to cost ratio is almost constant over the whole time period. However, since 1980, productivity growth has only partially compensated for the deteriorating terms of trade, leading to lessened profitability for prairie agriculture.

V. Summary and Conclusions

This final technical project report is focussed on the role of capital and capital formation in production, productivity, and competitiveness in Canadian agriculture. The emphasis is on the prairie region of Western Canada. The time period covered in the study is from 1948 to 1992, with the focus on the 1970s, 1980s, and early 1990s. The report considers productivity and the role of technological change, economies of scale, and other features of the structure of production. The report also includes a number of important issues pertaining to the measurement of both the capital stock and productivity in prairie agriculture.

The analysis of investment flows and capital stocks data performed in Section II indicates an important increment in the capital stock of farm machinery in the 1970s and a modest increment in the stocks of capital related to agricultural land and buildings over the whole period. Changes in the input mix result from the initial substitution of capital for labour and a rising share of materials including agri-chemicals. The land input appears to change little and slowly. Land related investment and repairs also show a slow but steady growth over the period. In the 1980s, the estimated labour share slowly rises, reversing its historical downward trend. Both the machinery increment and the rise in land investments seem to be related to technological factors, broadly interpreted to include economies of scale and organizational and agronomical practices.

The most important development appears to be the important increase in investments in the 1970s, particularly in farm machinery, and the resulting increments in capital stocks. The period after the mid 1980s exhibits a considerably slow down in the rate of investment in agriculture, in the Prairies and Alberta as well as in Canada. This suggests that dis-investment took place in the late 1980s and early 1990s. Analysis of machinery related prices and of the de-inflated time series of capital stocks indicate that some dis-investment has occurred, although it appears to be of a relatively modest proportion. This is particularly so if it is related to effects on productive capacity which is the appropriate yardstick to be used. Higher input prices, particularly for certain machinery items such as combines and for agricultural building, were regarded as indications of improved technical features of these items. Since both productivity and total output do not appear to be shrinking, productive capacity does not appear to have been affected by lower levels of investment in the 1980s. The simple analysis of capital stock data and investments flows suggests that enhanced productivity, through technological change and economies of scale, are in part compensating for the reduced investments in the last years of the period.

In Section III a translog cost function was estimated for prairie agriculture over the period 1948-1991. Cost function parameters, elasticities of derived demand for inputs, and Allen partial elasticities of input substitution were calculated. The results indicate an increasingly rigid production structure in the 1970s and early 1980s, in agreement with previous estimates. The agricultural production technology exhibits trends toward lower elasticities of derived input demand and reduced input substitution. Such trends suggest that technology in prairie farming was becoming a "technological package", that is to say, a technology characterized by a more or less fixed input bundle. The predominance of inelastic factor demands, with the exception of chemicals, implies that the possibilities of altering the structure of production by prices alone is not present. The trend to increasing rigidity was modestly reversed in the late 1980s when a slowly changing input mix resulted from reduced use of chemicals and machinery. These changes may be related to changing economic conditions which generally favoured cost reduction as opposed to output expansion as in the previous period. The relatively slow response of the system, however, indicates the persistence of rigidities and narrow input choices for farmers.

Further analysis of the structure of the underlying technology centred on statistically testing functional properties of the cost function. Test results indicate rejection of homotheticity, of constant return to scale, and of Hicks neutrality. The findings concerning non-homotheticity, the biases in technological change, and the presence of scale economies are an indication of the complex structure of technology in prairie agriculture. Further research in this area is certainly of interest. The findings concerning the existence of inelasticites and rigidities in the farming system is of course not a big surprise or entirely new. Agriculture has historically been moving in that direction for decades. What is interesting, however, is the recent modest reversal of these tendencies. It is not yet clear whether the increased flexibility which has occurred in prairie agriculture in the late 1980s is the start of a new trend or a temporary reversal in the historical trend towards greater rigidity.

In Section IV, the issue of index number methodology in the empirical measurement of agricultural productivity was analyzed. The major problems arise in the measurement of the input side, specially "durable" capital items. Aggregation or indexing procedures is another important conceptual issue. Given the conceptual superiority of flexible indexes and the divergences in estimated productivity growth rates between flexible and fixed base indexes, we would recommend that Divisia-based or chained Fisher indexing be employed rather than traditional indexes such as the Laspeyres or Paasche. Further, our empirical results suggest there is little practical difference in productivity estimates based on the Tornqvist-Theil approximation to the

Divisia index as opposed to the Fisher "ideal" chained index. Either of these improved flexible indexing procedures can be regarded as being suitable for the practical purpose of productivity comparisons across time or region.

In summary, the evidence and results of the studies in this report suggest that the farming system in western Canada has been experiencing important transformations in the last two decades in our period of study. In terms of the structure of production technology, our findings indicate non-homotheticity, biased technical change, and a more important role for economies of scale. In addition to the problem of measurement of the capital input in productivity estimation, the use of flexible forms, such as Divisia or Fisher Chained procedures, is preferred. In terms of the productive role of capital stock, it appears that the agricultural system, having achieved a new ceiling in investment in the 1970s, went through a process of adjustments and correction in the second half of the 1980s. This process resulted in an overall reduction in the annual level of investments and a shrinkage in the capital stock mostly due to a decline in the farm machinery component.

This process and the associated dis-investment do not seem to have translated into a reduction in productive capacity. Our results suggesting the presence of biassed technical change and of economies of scale may be helpful in explaining such occurrence. Rather, the change in the input mix seems to indicate an adjustment to new economic conditions and new farming modalities and practices along with technical change, economies of scale, and the reduction in the number of farms, but of a larger size. Any dis-investment that may have occurred is of modest proportions except for machinery. Even a reduced machinery stock seems to have had little effect on productive capacity and productivity in the short run. Given the large drop in investment levels, it is possible that in the long run we would witness reductions in productive capacity as machinery items depreciate. It is not possible to ascertain, given the limited data available, if the level of investment prevailing in the last years of the period are appropriate to compensate for capital depreciation. Only future availability of data may provide a more definite answer. Nevertheless, if the level of investment and repairs is adequate for the maintenance of the machinery stock, no reduction in production capacity is to be expected from these factors.

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