University of Alberta

Measures and Causes of Productivity Growth in Prairie Agriculture: 1940-2004

by

Bryce Edward Roger Stewart ©

A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science in Agricultural and Resource Economics

Department of Rural Economy

Edmonton, Alberta
Fall 2006

Your file Votre référence
ISBN: 978-0-494-22379-6
Our file Notre référence
ISBN: 978-0-494-22379-6

ABSTRACT

This study undertakes a comprehensive analysis of productivity growth in Prairie agriculture. Over the 1940 to 2004 period productivity growth in Prairie agriculture grew at a rate of 1.56 percent a year. This aggregate measure does not indicate the substantial variation in productivity growth occurring: the crops sector records considerably higher productivity growth than the livestock sector; Manitoba agriculture displays consistently higher productivity growth than Alberta or Saskatchewan; from 1980 to 2004 productivity growth in the livestock sector increases, and it declines in the crops sector from 1994 to 2004 in Alberta and Saskatchewan. The productivity growth is largely the result of technical change in the crops sector while economies of scale play a critical role in generating productivity growth in the livestock sector. Causal factors responsible for the reported agricultural productivity growth rates include: research and development expenditures, terms of trade, types of agricultural outputs, and geoclimatic conditions.

ACKNOWLEDGEMENTS

This study is the result of over a years' work. During this time a number of individuals have offered their support, encouragement, and expertise ensuring the project's completion. Firstly, I am grateful for the contributions of the faculty, staff and students of the Department of Rural Economy. They have made the last two years of course work and research at the University of Alberta a rewarding experience, and have helped me develop professionally and personally. I would especially like to thank Robin and the front office staff who through their efforts have made my life as a graduate student an easy one.

The idea behind this study was originally developed by my thesis supervisor Terry Veeman whose wealth of knowledge and experience is deeply valued. I owe a debt of gratitude to my co-supervisor Jim Unterschultz who has encouraged me to focus on the real world significance of the research and concentrate on the study's objectives. The study has profited from the enthusiastic support and input of Terry and Jim at all stages. Their guidance and suggestions, and insight into Prairie agriculture have been invaluable. Of course, any omissions and errors are mine alone.

I would like to acknowledge the support of my family. My parents continue to offer support and encouragement regardless of the direction I take. One's decisions are never made in a vacuum and my sister Amber's encouragement and success in graduate school were the genesis of my decision to pursue graduate studies.

Most of all, thanks are due to Jane for editing papers, posters, and helping with presentations. Jane's love, support, and insights have sustained my academic endeavours and critical thinking, while helping me remain grounded. Any success I enjoy is shared with her.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 Introduction

The intent of this study is to undertake a comprehensive examination of productivity growth in Prairie agriculture over the 1940 to 2004 period. The critical role that productivity growth plays in Prairie agriculture is illustrated early in Chapter 1, and indicates the rationale for pursuing the study's research program. In the remainder of Chapter 1 the study's research program is outlined: specifically, the measurement of Prairie agricultural productivity growth, and the evaluation of how and why productivity growth has occurred as it has.

Productivity growth is the growth in outputs produced not accounted for by the growth in the inputs used in the production process.[1] For example, if outputs produced (e.g. bushels of wheat) grow at a rate of three percent per annum while inputs used in the production process (e.g. fertilizer and seed) increase at a rate of only one percent a year then productivity growth of two percent a year occurs (3% - 1% = 2%). In this sense productivity growth is a residual measure that accounts for the influence of non-input factors on output production (e.g. improved technology).

Productivity growth is a key determinant of the economic growth of an economic activity constrained by relatively scarce resources. Consequently productivity growth is a critical component of agricultural output growth. For U.S. agriculture, over the 1948-1979 period, Ball (1985) estimates that 88 percent of growth in output was due to productivity growth (as opposed to growth in inputs). In terms of Prairie agriculture, Veeman, Fantino and Peng (1998) found that productivity growth accounted for 86 percent of the growth in output for the 1948-1994 period. Beyond its impact on output growth, productivity growth has implications for the competitive position of the agricultural sector and its long-run prospects. Simply put, if you can do the same or better with less, *ceteris paribus*, you are in a superior competitive position. A more

---

[1] This description follows Solow's seminal model of growth accounting, which arose from his neoclassical model of growth (Solow, 1957).

profound understanding of productivity growth in Prairie agriculture will serve to inform superior policy intended to ensure this vital sector's long run economic sustainability.

Prairie agriculture enjoyed substantial productivity growth over the 1948-1994 period at an aggregate level. However, when overall agriculture productivity growth was disaggregated Veeman *et al* (1998) found that productivity growth in Alberta was somewhat lower than that found in overall Prairie agriculture. More significantly, productivity growth in Alberta livestock lagged substantially behind productivity growth in Alberta crops.[2] Productivity grew at 2.75 percent per annum in crops compared with only 0.81 percent per year for livestock. The economic importance of productivity growth makes the divergence between provinces and between crops and livestock a matter of significant interest, and informs the purpose and scope of the three sub-objectives of this study.

1.2 Objectives

The overall objective of the study is to evaluate productivity growth in Prairie agriculture over the 1940 to 2004 period. For analytical clarity this overarching objective is divided into the following three sub-objectives:

- Obtain aggregate and disaggregated productivity growth estimates for Prairie agriculture.
- Identify the respective roles of scale and technical change in productivity growth, and the salient productivity related characteristics of the production structure underlying Prairie agriculture.
- Assess causal factors responsible for productivity growth.

The first sub-objective of this study is to refine and extend the productivity growth estimates of Veeman *et al* (1997 and 1998). Farm level productivity growth will be estimated over the 1940 to 2004 period, for the Prairies, Alberta, Saskatchewan and Manitoba. Productivity growth will also be estimated for the livestock and crops

[2] These results are consistent with the findings of Huffman and Evenson (1993) for United States agriculture.

agriculture in each province and for the Prairies. The productivity estimates form the basis for analyzing differences in productivity growth over time, among provinces, and between crops and livestock.

The second sub-objective is to assess *how* productivity growth has occurred. Productivity growth can be decomposed into three components: technical change, scale effects and changes in the degree of technical efficiency. Technical change refers to technological progress in its broadest sense; it encompasses not only advances in physical technologies (e.g. improved machinery or crop genetics), but also innovations in the overall knowledge base that lead to better decision making and planning (e.g. reduced use of summer fallow in Manitoba). Scale effects point to economies in production that can be realized at certain scales of production. The presence of increasing economies of scale is an indication that the production of additional outputs will require a less than proportional increase in inputs. For instance, in the presence of increasing economies of scale acquiring additional crop acreage may be a productive decision for a producer. Overall, less inputs per unit of output will be required, perhaps, for example, because farming the extra land does not require the purchase of additional machinery, since the existing machinery can be used more intensively. Conversely, with decreasing economies of scale productivity improvements can be realized by reducing the scale of production. Improvements in the degree of technical efficiency point to situations where resources can be used more efficiently by applying practices from the present stock of knowledge (e.g. seed use can be reduced if best practice seed spacing is employed).

Throughout this study technical efficiency is assumed and the analytical focus rests on the roles of scale and "pure" technical change. The relative roles of technical change and scale are indicative of the potential causes of productivity growth and the impact that different policies may have on growth. For example, productivity growth composed largely of scale effects points to structural change in the agricultural sector as the driver of productivity growth, and policy designed to retard structural change may impede productivity growth. Conversely, if technical change is found to play a dominant role, it suggests the primacy of technology development and adoption in productivity advance, and points to research and development as an optimal policy tool to stimulate productivity growth. Decomposition of the productivity growth estimates will also offer explanations for varying productivity growth rates over time. For example, a period of exceptionally rapid productivity advance may be correlated with a period of substantial technical change. Lastly, an analysis of the production structure of Prairie agriculture will offer further insight into the nature of productivity growth. For example, determining the bias of technical change (e.g. whether it is labour saving or capital using) will allow further refinement of plausible explanations for productivity growth or stagnation over time.

This study's third sub-objective is to assess *why* productivity growth has occurred; that is, to determine what underlying causal factors account for agricultural productivity growth over the 1940 to 2004 period. There are a number of plausible hypotheses for the productivity growth realized; they range from quantitative explanations, such as expenditures on research and development, to qualitative explanations, such as specific geoclimatic and socio-economic conditions.

By realizing the study's three sub-objectives a detailed assessment of productivity growth in Prairie agriculture is possible. The result is an examination of the nature of productivity growth which can be used to inform policy required to maintain the long run economic sustainability of Prairie agriculture.

1.3 Outline

Table 1.1 Outline of Study Contents

Chapter 1:	Introduction and problem definition
Chapter 2:	Productivity measurement methodology
Chapter 3:	Productivity decomposition and production structure modeling methodology
Chapter 4:	Input/output data set
Chapter 5:	Empirical results I: productivity measurement
Chapter 6:	Empirical results II: productivity decomposition and production structure
Chapter 7:	Causal analysis of productivity growth
Chapter 8:	Conclusions and policy implications

In Chapter 2 the non-parametric or index number methodology employed in the measurement of productivity in this study is reviewed. First, the theoretical preference for using total factor productivity (TFP) as a measurement of productivity is outlined. Second, the use of Törnqvist-Theil indexing as the indexing procedure of choice in measuring TFP is addressed. Although the non-parametric estimation of productivity conducted in this study is empirically straightforward, the theoretical basis justifying this approach is conceptually involved, and some detail is required to make explicit the assumptions implicit in this methodology.

The theory presented in Chapter 2 is extended in Chapter 3 by illustrating how productivity estimates obtained non-parametrically can be decomposed econometrically into scale effects and technical change using neoclassical theory of the firm and duality concepts. Conceptual issues underlying the economic modeling of the agricultural sector, data requirements, and key assumptions required to operationalize the model are also reviewed. Using production theory, a number of measures, relevant to the study, will be recovered concerning the agricultural industry's production structure, and their economic significance and interpretation will be discussed. Specifically:

- The changing rates of technical change and returns to scale over time.
- The bias of technical change (e.g. labour or capital saving).
- The presence of (dis)economies of scope.

In short, the theory and modeling required to explain *how* productivity growth happens is presented in Chapter 3.

Chapter 4 contains a comprehensive account of the agricultural input and output data used in the subsequent empirical analysis. There are a number of compelling reasons for the in-depth analysis of the data. First, on a practical level, a description (both numerical and graphical) of the data provides important background information yielding a broad quantitative portrayal of agriculture in the three Prairie provinces over the 1940 to 2004 period. Second, the compilation of data for the agricultural inputs and outputs of Prairie agriculture is a major empirical and conceptual challenge and the rationale and methodology behind its construction warrants detailed assessment, particularly as regards the allocation of inputs between crops and livestock agriculture. Thirdly, the estimates of productivity growth and the ancillary analysis are all extremely data intensive and thus the results and their interpretation (as in any empirical investigation) depend, to a great extent, on the veracity of the data, in addition to the choice of a theoretically appropriate model. In this sense, the devil may indeed be in the details, and great care should be taken in delineating the construction and assumptions implicit in the data. It is recognized that any extended description of the data used in an empirical investigation leaves one open to criticism; there is seldom a unique approach in the construction of the data required to conduct any significant applied economic research. Nevertheless, in Chapter 4 a substantive effort is made to ensure that the data and the methodology used in constructing the data are explained in detail, for the reasons considered above, and because a detailed description of the data will facilitate future inquiry (i.e. conducting a similar analysis for other provinces and over different time periods) and permit more effective comparison with other related studies.

In Chapter 5 the empirical results of the inquiries outlined in Chapter 2 are reported: specifically, index number input/output and productivity growth estimates. Terms of trade and returns to cost, measures that reflect industry cost pressures and relative profitability, are also reported. The results are discussed, with a focus on their variability over time and on the differences between the results reported for crops and livestock activities and amongst the individual provinces. The discussion provides a broad outline regarding the agricultural productivity growth that has occurred over the last sixty-five years in the three Prairie provinces. The productivity estimates also provide the basis for the analysis undertaken in Chapter 6.

The empirical results for methodologies illustrated in Chapter 3 are recorded in Chapter 6. The productivity growth estimates of Chapter 5 are decomposed into scale effects and technical change in Chapter 6, in order to examine their respective roles. Additional measures relating to the production structure of Prairie agriculture are also recorded and analyzed. The discussion that follows explores the structure of Prairie agriculture, showing how productivity growth has occurred, and substantiates the appropriate direction to follow in determining probable causal explanations for the productivity growth. The results and analysis in Chapters 5 and 6 provide the starting point for the assessment of the causes of productivity growth in the following Chapter.

In Chapter 7 various determinants of the measured productivity growth are assessed, with a focus on arriving at explanations for the divergent productivity growth rates in crops and livestock, between the Prairie provinces, and over time. First of all, a number of potential causes for the productivity growth are evaluated qualitatively. The qualitative analysis sets the stage for a statistically rigorous investigation of quantifiable explanations. The econometric model employed in testing the quantitative explanations is reviewed and the model's results reported. Chapter 7 concludes with a review of probable causal elements responsible for agricultural productivity growth in the Prairie by synthesizing the qualitative and quantitative findings.

In the final Chapter, Chapter 8, conclusions are established regarding productivity growth in Prairie agriculture. How and why has productivity growth occurred in the past? What are the implications for productivity growth in Prairie agriculture entering the twenty-first century? This discussion forms the basis for comment on policy options amicable to future productivity growth. Finally, in Chapter 8 the limitations of the study and directions for further research are explored.

CHAPTER 2: PRODUCTIVITY MEASUREMENT METHODOLOGY

2.1 Introduction

This study is focused on productivity growth in Prairie agriculture – assessing how it occurs and its potential causes. Consequently, the accurate measurement of productivity is central to the analysis, and the choice of an appropriate methodology to use in measuring productivity growth is critical. In this study total factor productivity (TFP) is chosen as the appropriate conceptual measure of productivity and the Törnqvist-Theil index number (growth accounting) procedure is employed to derive TFP estimates. This Chapter will outline the rationale behind using index number procedures generally, and the Törnqvist-Theil index specifically, in measuring productivity growth.

2.2 Background

At first blush, the aggregation of economic data, required for most any empirical economic study, would appear to be a conceptually simple though perhaps practically difficult task. Given a complete set of prices and/or quantities their aggregation would appear to be no more than a straightforward accounting exercise. Nonetheless, any method chosen to aggregate data involves the imposition of assumptions. The index number or growth accounting approach to TFP measurement is no exception, since it relies on the aggregation of a number of inputs and outputs in its calculation. The objective of this Chapter is to explore the theoretical underpinnings of effective TFP measurement and assess the strengths and weaknesses of the growth accounting approach to TFP estimation. To this end, a description of TFP measurement and its implications is undertaken, and the two conventional approaches used in its measurement are examined. The analysis that follows focuses on using the growth accounting approach to estimate TFP. Different methods, or indexing procedures, involved in the aggregation of data are evaluated, including a superior indexing procedure that permits effective TFP measurement. Issues regarding the index number approach to TFP measurement are then addressed, with the goal of delineating sources of potential bias in TFP calculation.

Finally, an overall appraisal of the growth accounting approach to TFP measurement is conducted.

2.3 Total Factor Productivity (TFP) Measurement

TFP measures the change in physical outputs of a production process which cannot be accounted for by a change in the physical inputs. In this sense TFP is a residual measure that is indicative of the overall technical efficiency and productivity of an economic entity. TFP is a conceptually superior measure of productivity than measures of partial productivity. Partial productivity measures, such as productivity per person hour of labour, are subject to bias because they do not account for the substitution between inputs (Christensen, 1975).[3] During periods marked by significant changes in the relative prices of inputs, substitution between factors can be considerable. The practical significance of TFP measurement is the wealth of information it can provide to policy makers: for example, the identification of the determinants of economic growth, measurement of technological change, and determination of intersectoral (and international) economic performance (Thirtle and Bottomley, 1992). From an economic perspective, TFP can be decomposed into three measures: scale impacts, degree of technical efficiency, and the state of technology (Capalbo, 1988). This yields substantive insight into the nature of productivity growth, or lack thereof. In the context of agriculture, this information is vital to lesser developed countries where agriculture is their most significant industry, but it is also essential in developed nations where the determination of appropriate agricultural policy continues to be contentious. While growth in agricultural productivity is not a sufficient condition to ensure the economic sustainability of Prairie agriculture, it is certainly a necessary condition, particularly in

---

[3] The following simple example illustrates the potential shortcomings of partial productivity measures. Suppose a firm upgrading its plant and equipment installed new, more technologically advanced (productive), machinery. If a partial productivity measure such as productivity per hour of labour is employed, the acquisition of the new machinery will appear as a growth in labour productivity, since greater output per hour of labour occurs due to the new equipment. However, strictly speaking, the productivity gain is the result of the new machinery, and consequently a portion of the productivity advance should be attributed to machinery, rather than entirely to labour as the productivity per hour of labour partial productivity measure implies.

the face of this sector's long run declining terms of trade (see Table 5.1). Empirically, the importance of TFP is clearly confirmed by the majority share it comprises in the overall growth of Prairie agricultural output. Sixty-four percent of the growth in agricultural output is the result of productivity growth (increased input use is responsible for the remaining thirty-six percent) (see Table 5.1). The study of TFP is critical to understanding the long run competitive position of Prairie agriculture, and accurate TFP measurement is a prerequisite in this regard.

There are two principal approaches in the measurement of TFP. The first is the non-parametric growth accounting or index number approach, and the second is the econometric approach.[4] The two methods complement each other since neoclassical economic production theory underpins their interpretation. In this sense, either method can be used to validate the results obtained by using the alternate approach. This Chapter focuses on the index number approach to TFP measurement, thus a brief discussion of the strengths and weaknesses of both methods is required to set out the rationale for choosing the index number approach over the econometric method.

2.3.1 Econometric Measurement of TFP

The econometric method's greatest strength is also its greatest weakness, namely its statistical underpinnings. The econometric method involves the estimation of the production technology and measuring the shift in either the production or cost function (Antle and Capalbo, 1988). Gains are realized by being able to relax some of the assumptions required by the index number approach (e.g. industry equilibrium). This approach is also amenable to the use of statistical tools, such as confidence intervals and related reliability measures. However, Capalbo (1988) points out that the cost of using the econometric approach is that input-output separability must be assumed, since outputs need to be aggregated into a single index. Moreover, to ensure sufficient degrees of freedom and reduce multicollinearity problems, multiple inputs typically need to be aggregated into a smaller number of categories. This is particularly true when dealing

---

[4] Other non-parametric methods (e.g. Data Envelopment Analysis) can be employed in efficiency or productivity analysis using cross-sectional or panel data and mathematical programming approaches (Coelli *et al,* 1998).

with a short time series. Consequently, some degree of input separability must also be assumed.[5]

2.3.2 Index Number Measurement of TFP

The index number approach is not limited by the number of inputs and outputs. This is a significant advantage. Even in a simple productivity study, the number of inputs, if not outputs, can be quite substantial. Nor is the index number approach limited by degrees of freedom issues, since it can be used with a minimum of two data points. However, the index number approach is not amenable to the statistical analysis which can be employed with the econometric approach. As mentioned earlier, the index number approach also requires somewhat stronger assumptions. Specifically, it assumes competitive behaviour on the part of firms, Hicks-neutral technical change[6], and that a functional form exists that can represent the production technology under a range of different prices and quantities (Antle and Capalbo, 1988). Nevertheless, advances in index number theory and functional forms over the last 35 years have permitted the relaxation of many of the assumptions required under the index number approach.

---

[5] Depending on the production process, input-output separability can be quite a strong assumption. Many examples can be thought of where the changing magnitudes of different outputs will affect the efficient allocation of inputs (Christensen, 1975). In addition, determining the appropriate groupings of inputs can be quite difficult, particularly in agriculture, where many inputs are shared in the production of multiple outputs.

[6] Hicks-neutral technical change is technical change that does not alter the respective factor shares involved in the production process. Hicks-neutral technical change can be quite a restrictive assumption, since it is typically anticipated that technological progress is not neutral with regard to factor shares. Technological progress is generally viewed as being labour saving and capital using, as production processes become increasingly mechanized and less labour intensive.

2.4 Simple Indexing Procedures: Laspeyres and Paasche Indexes

The growth accounting or index number method of TFP calculation can be written as:[7]

$$TFP = \left(\frac{Q_t}{Q_{t-1}}\right) \Big/ \left(\frac{X_t}{X_{t-1}}\right)$$

where (Q_t / Q_{t-1}) is the change in aggregate output and (X_t / X_{t-1}) is the change in aggregate input. To calculate TFP a method needs to be employed to arrive at two numbers: a number reflecting the change in outputs over the two periods (Q_t / Q_{t-1}), and another number reflecting the change in inputs over the two periods (X_t / X_{t-1}). Indexing procedures perform this task.

Section 2.3.1 and 2.3.2 indicated that the index number approach to TFP measurement enjoys some advantages over the econometric approach. Nonetheless, in order to minimize the deficiencies of the index number approach, an appropriate indexing procedure must be used to aggregate inputs and outputs relating to a production process. Since the indexing procedure chosen implicitly imposes a series of (economic) assumptions on the data, the goal is to choose an indexing procedure which reflects the most realistic, yet theoretically tractable, assumptions possible. The first, and one of the oldest, indexing procedures that is discussed is the Laspeyres.[8]

The Laspeyres index incorporates a number of very restrictive assumptions, and for this reason an assessment of its shortcomings is instructive.[9] Through its simplicity, an intuitive analysis of indexing issues in general can be pursued. A Laspeyres quantity index can be written as:

---

[7] By taking the logarithm of the simple TFP function, and differentiating it with respect to time, an approximation of the TFP growth rate can be obtained (Salami, 1996).

[8] Although a very old indexing procedure Kohli (2004) points out that the Laspeyres quantity index is still used in the measurement of GDP by a large number of nations.

[9] In the following discussion Laspeyres and Paasche input quantity indexes are dealt with. However, the analysis is generalizable to output quantity indexes and price indexes.

$$\frac{X_t}{X_{t-1}} = \frac{\sum_{i=1}^{n} p_{i,t-1} x_{i,t}}{\sum_{i=1}^{n} p_{i,t-1} x_{i,t-1}}$$

where X_t is total input in period t and X_{t-1} is total input in period $t-1$, the base period. The Laspeyres quantity index measures the increase in the quantity of inputs by holding input prices fixed at the base period.

A criticism of the Laspeyres index is that it uses base period prices to calculate the pure quantity change in aggregate inputs over separate periods. Input quantities in period t are related to period $t-1$ prices. The effect that period t prices have on period t quantities is disregarded, since base period prices are used as weightings for both periods. As Christensen (1975) points out, the Laspeyres index implies an underlying linear production function, in which inputs are perfect substitutes (an infinite elasticity of substitution). The implication is that prices need to be fixed at the base period precisely because a change in the relative price of one input would cause complete substitution away from it, in the case of a price increase, or towards it, in the case of a price decrease.

In reality, few production processes have inputs which are perfect substitutes. It may be a little easier to see output as being responsive to price changes. However, anything approaching perfect price responsiveness is not an accurate portrayal of most any industry's output supply function. Consequently, the Laspeyres index is subject to substitution bias, as is the closely related Paasche index.

Similar criticisms apply to the Paasche index, which is identical to the Laspeyres index except that end periods are used for weighting, instead of base periods. The Paasche input quantity index can be written as follows:

$$\frac{X_t}{X_{t-1}} = \frac{\sum_{i=1}^{n} p_{i,t} x_{i,t}}{\sum_{i=1}^{n} p_{i,t} x_{i,t-1}}$$

Rather than implying inputs which are perfect substitutes, the Paasche input quantity index implies a Leontief production function where inputs are perfect complements (elasticity of substitution of zero) (Antle and Capalbo, 1988). Intuitively, a production function exhibiting these characteristics may provide an approximation of some industries with very high fixed costs. Still, the assumptions are far too rigid to provide an accurate representation of reality.

There is also a general criticism that can be made of the Laspeyres and Paasche indexes. It relates to their choice of base period and end period weightings. It is not clear which period should be chosen as a weight in aggregation, and the use of either period will bias the results. For example, during periods of rising prices, the Laspeyres quantity index's use of base period weights will lead it to understate the amount of quantity change while the Paasche approach of using end period prices will tend to overstate its measurement of quantity change (Fisher and Shell, 1998). Furthermore, since both Laspeyres and Paasche indexes are defined relative to their respective base and end periods, any multilateral comparisons of runs in these indexes may be suspect if they are using different base periods (Kohli, 2004).[10] This problem can be solved by chaining the indexes. In the case of the Laspeyres, for example, chaining involves continually resetting the base period; the current period becomes the base period for the subsequent period, and so on. Chaining also possesses other advantages: no one period plays a disproportionate role in the indexing procedure, and periods before and after the introduction (removal) of a new input can be effectively compared (Diewert, 1987).

2.4.1 TFP Measurement Using Laspeyres and Paasche Indexes

The criticisms made of the Laspeyres and Paasche indexes, have implications for TFP measurement. Using the Laspeyres quantity indexes, TFP can be written as:

$$(2.1) \quad TFP = \left(\frac{\sum_{j=1}^{m} w_{j,t-1} q_{j,t}}{\sum_{j=1}^{m} w_{j,t-1} q_{j,t-1}} \right) \Bigg/ \left(\frac{\sum_{i=1}^{n} p_{i,t-1} x_{i,t}}{\sum_{i=1}^{n} p_{i,t-1} x_{i,t-1}} \right)$$

---

[10] The importance of which base period to use is underlined by Diewert's (1992) observation that productivity measurement in economics is a relative concept, unlike the absolute measures of productivity used in engineering studies. Therefore, determining what period a specific measure is relative to is crucial.

Following Christensen (1975), the revenue share of output j, and cost share of input i, can be written as:

$$r_{j,t-1} = \frac{w_{j,t-1} q_{j,t-1}}{\sum_{j=1}^{m} w_{j,t-1} q_{j,t-1}}$$

$$s_{i,t-1} = \frac{p_{i,t-1} x_{i,t-1}}{\sum_{i=1}^{n} p_{i,t-1} x_{i,t-1}}$$

and since,

$$\frac{\sum_{j=1}^{m} w_{j,t-1} q_{j,t}}{\sum_{j=1}^{m} w_{j,t-1} q_{j,t-1}} = \frac{\sum_{j=1}^{m} w_{j,t-1} q_{j,t} \cdot \dfrac{q_{j,t-1}}{q_{j,t-1}}}{\sum_{j=1}^{m} w_{j,t-1} q_{j,t-1}} = \frac{\sum_{j=1}^{m} w_{j,t-1} q_{j,t-1} \left(\dfrac{q_{j,t}}{q_{j,t-1}} \right)}{\sum_{j=1}^{m} w_{j,t-1} q_{j,t-1}} = \sum_{j=1}^{m} r_{j,t-1} \left(\frac{q_{j,t}}{q_{j,t-1}} \right)$$

$$\frac{\sum_{i=1}^{n} p_{i,t-1} x_{i,t}}{\sum_{i=1}^{n} p_{i,t-1} x_{i,t-1}} = \frac{\sum_{i=1}^{n} p_{i,t-1} x_{i,t} \cdot \dfrac{x_{i,t-1}}{x_{i,t-1}}}{\sum_{i=1}^{n} p_{i,t-1} x_{i,t-1}} = \frac{\sum_{i=1}^{n} p_{i,t-1} x_{i,t-1} \left(\dfrac{x_{i,t}}{x_{i,t-1}} \right)}{\sum_{i=1}^{n} p_{i,t-1} x_{i,t-1}} = \sum_{i=1}^{n} s_{i,t-1} \left(\frac{x_{i,t}}{x_{i,t-1}} \right)$$

TFP can also be written as:

$$(2.2) \quad TFP = \left(\sum_{j=1}^{m} r_{j,t-1} \left(\frac{q_{j,t}}{q_{j,t-1}} \right) \right) \Big/ \left(\sum_{i=1}^{n} s_{i,t-1} \left(\frac{x_{i,t}}{x_{i,t-1}} \right) \right)$$

Equation (2.2) shows that both input cost and output revenue shares remain constant over both periods in this calculation of TFP, a very strong assumption. By examining equation (2.1) it is apparent that the Laspeyres factor substitution bias will be found in both the denominator and numerator, creating inaccuracies in TFP measurement. Depending on the relative movement of output and input prices, TFP may be further biased. For example, let input prices be higher in period t than in period t-1, and let output prices be lower in period t than in period t-1. Because of the Laspeyres base period price weighting, the change in input quantities (denominator) will be understated, while the change in output quantities (numerator) will be overstated. In this case, the Laspeyres TFP estimate will be too high.[11]

2.5 Alternative Indexing Procedures

Given the inherent weaknesses of the traditional Laspeyres and Paasche indexes, the examination of alternate indexing procedures is required. In this context it is useful to explore the two approaches typically used in choosing suitable indexes.

2.5.1 Axiomatic Approach to Choosing Indexing Procedures

The first method is referred to as the axiomatic or test approach. This approach involves the specification of a number of mathematical axioms that a well-behaved indexing procedure should meet. An example of one of the axioms is the *product test,* which can be written as follows (Diewert, 1992):

$$P(p_t, p_{t-1}, y_t, y_{t-1}) \cdot Q(p_t, p_{t-1}, y_t, y_{t-1}) = \frac{R_t}{R_{t-1}}$$

$P(p_t,p_{t-1},y_t,y_{t-1})$ is the price index and $Q(p_t,p_{t-1},y_t,y_{t-1})$ the quantity index between periods t and $t\text{-}1$. Their product should equal R_t / R_{t-1}, the revenue ratio between the two periods. The *product test* and a number of other fundamental tests (i.e. the *constant prices test. constant quantities test, time reversal test,* and the *proportionality in period t prices test*) all share an intuitive appeal, since they display reasonable properties that would be expected from an effective indexing procedure (Diewert, 1992). Nevertheless, most indexing procedures do not pass all the tests, the Fisher's ideal index being the exception.[12] The Laspeyres and Paasche indexes both fail the *time reversal test*, and the Törnqvist-Theil index fails the *constant quantities test* (Diewert, 1992). However, Fisher and Shell (1998) point out that it is always possible to come up with another reasonable test that an indexing procedure can not pass, since a vector must lose some information in its transformation into a scalar. The problem lies in determining which axioms are most relevant to the success of an indexing procedure in light of its proposed use.

---

[11] The opposite results would hold if a Paasche index was used to measure TFP.
[12] Fisher's ideal index, which is the geometric average of the Laspeyres and the Paasche indexes, also passes a number of other axiomatic tests (Diewert, 1987).

2.5.2 Exact Index Number Approach to Choosing Indexing Procedures

The second method for determining an appropriate index number procedure is the economic or the exact index number approach. As Diewert (Diewert and Nakamura, 1993) points out, the economic approach is an axiomatic approach, only it relies on economic axioms. When discussing the Laspeyres and Paasche indexes, it was indicated that their underlying production functions are linear and Leontief respectively. In fact, it can be shown mathematically that the Laspeyres index is *exact* for the linear production function, while the Paasche index is *exact* for the Leontief production function (Diewert, 1987). According to Diewert (1981) a quantity index $Q(p_t, p_{t-1}, x_t, x_{t-1})$ is *exact* for a neoclassical aggregator function $f(.)$ where the following equality holds:

$$Q(p_t, p_{t-1}, x_t, x_{t-1}) = \frac{f(x_t)}{f(x_{t-1})}$$

where x_t and x_{t-1} are the vectors of input quantities for periods t and $t-1$.

A similar rationale underlies a price index being *exact* for a particular cost function. However, the *exact* relation between an index number formula and a functional form comes at a cost, since it imposes the assumption of perfectly competitive behaviour with regard to both inputs and outputs (Capalbo, 1986).[13] This assumption may be more or less accurate depending on the economic entity being analyzed.

Although Diewert's definition of exactness imposes some behavioural restrictions, it also proves to be a very powerful analytical tool in choosing between competing indexing procedures. It permits the choice of an index number formula and associated functional form that reflects an underlying production technology. Index number procedures can then be chosen with regard to the economic assumptions implicit in their associated functional forms. In this vein, a superior approximation of actual production behaviour (e.g. output supply and input demand) can be reached, while remaining consistent with economic theory.

---

[13] For example, Capalbo (1988) points out that the Törnqvist-Theil indexing procedure, which is *exact* for the translog functional form, uses cost and revenue shares. Cost and revenue shares require the use of Shepard's lemma in their derivation, and Shepard's lemma presupposes competitive behaviour, e.g. inputs are paid their marginal products.

The preceding analysis has dealt with the linear and Leontief production functions and found them to be too restrictive due to the imposition of perfect substitution or complementarity. Another candidate is the Cobb-Douglas production function for which the geometric index is *exact* (Diewert, 1987). The Cobb-Douglas production function, unlike the linear or Leontief production functions, permits differing (marginal) technical rates of substitution between the inputs to the production process, at different input ratios (Varian, 1992). This is a more accurate portrayal of most production technologies. However, there are also limitations associated with the Cobb-Douglas production function.[14] First, inputs can only be substitutes. It does not allow inputs to be complements, and a complementary relationship between some inputs may be a realistic characterization, especially in the short run. Second, it imposes a unitary elasticity of substitution, which causes the marginal rate of technical substitution to change at a rate identical to that of the factor ratio (a constant rate). Third, the Cobb-Douglas form restricts the production function to constant factor shares and fixed returns to scale. A unitary elasticity of substitution, fixed returns to scale and an appropriate estimate of factor shares might approximate a particular production technology at a specific point in time, but these assumptions appear untenable over time and in the presence of technical change. Attempts have been made to generalize the Cobb-Douglas function in order to reduce the restrictiveness of its assumptions. The constant elasticity of substitution (CES) function is one such attempt.[15] Although the CES function permits a non-unitary elasticity of substitution that can range from zero to infinity, as its name suggests, the elasticity of substitution remains constant, which is still a distinct shortcoming. It was the advent of flexible functional forms in the 1970s that allowed the restrictiveness of many of the assumptions regarding production technologies to be relaxed.

2.5.3 'Superlative' Indexes

A functional form can be termed flexible if it is a second-order approximation to an arbitrary linear homogeneous function (Capalbo, 1986). The translog is one such

---

[14] See Chambers (1988) for a detailed exposition of the properties of the Cobb-Douglas functional form.

[15] Given appropriate specification, the CES functional form can also be shown to collapse into a linear or Leontief function (Varian, 1992).

flexible functional form.[16] Its advantage is that it is a much more general functional form than the Cobb-Douglas. In fact, it is a generalization of the Cobb-Douglas function (Antle and Capalbo, 1988). Rather than placing *a priori* restrictions on the production technology, it permits a wide variety of production scenarios. For example, it allows inputs to be substitutes or complements and permits flexibility in the inputs' factor shares and elasticity of substitution. The generality, and hence realism, of the translog makes it a desirable representation of many different production technologies. However, in order to be employed in a growth accounting framework, there needs to be an indexing procedure that is *exact* for the translog functional form.

Diewert (1987) has defined any index number formula that is *exact* for a flexible functional form as *superlative*. Diewert was able to define a number of *superlative* indexes, including the Törnqvist-Theil index, a discrete approximation of the Divisia index, which is *superlative* for the linear homogeneous translog production function. As Caves, Christensen, and Diewert have shown, the Törnqvist-Theil index also turns out to be a *superlative* index for a number of very general production structures, such as non-constant returns to scale, nonhomogeneity, and even nonhomotheticity (Antle and Capalbo, 1988; Rosegrant and Evenson, 1992).

2.5.4 TFP Growth Measurement Using Törnqvist-Theil Indexing

Following Capalbo (1988), the proportionate rate of TFP growth can be written as:

$$(2.3) \quad \dot{TFP} = \dot{Q} - \dot{X}$$

where $\dot{Q}$ and $\dot{X}$ are, respectively, the proportionate growth rates of output and input. When considering multiple outputs and inputs an indexing procedure is employed to

[16] Other flexible functional forms include the generalized Leontief, quadratic mean of order rho, and generalized Cobb-Douglas (Thompson, 1988). This paper will deal solely with the translog function. It has been used extensively in empirical work, found generally acceptable, and there is a large body of literature surrounding its use.

aggregate diverse outputs and inputs into unique output and input indexes. Employing a Divisia index yields the following expressions:[17]

$$(2.4) \quad \dot{Q} = \sum_{j=1}^{m} \frac{p_j q_j}{R} \dot{q}_j \qquad \text{where } \dot{q}_j = \frac{\partial q_j / \partial t}{q_j}$$

$$(2.5) \quad \dot{X} = \sum_{i=1}^{n} \frac{w_i x_i}{C} \dot{x}_i \qquad \text{where } \dot{x}_i = \frac{\partial x_i / \partial t}{x_i}$$

where $\dot{q}_j$, p_j and q_j are, respectively, the growth rate, price, and quantity of the j^{th} output and R is total revenue; $\dot{x}_i$, w_i and x_i are, respectively, the growth rate, price, and quantity of the i^{th} input and C is total cost. The discrete approximation to equation (2.3) using the Törnqvist-Theil index can be written as:

$$(2.6) \quad \dot{TFP}^T = \dot{Q}^T - \dot{X}^T$$

where,

$$(2.7) \quad \dot{Q}^T = \sum_{j=1}^{m} \left(\frac{r_{j,t} + r_{j,t-1}}{2} \right) \left[\ln q_{j,t} - \ln q_{j,t-1} \right]$$

$$(2.8) \quad \dot{X}^T = \sum_{i=1}^{n} \left(\frac{s_{i,t} + s_{i,t-1}}{2} \right) \left[\ln x_{i,t} - \ln x_{i,t-1} \right]$$

$r_{j,t}$ is the revenue share of output j in period t, and $s_{i,t}$ is the cost share of input i in period t. The use of flexible input and output factor share weights in the Törnqvist-Theil index is apparent. They are an arithmetic average of the revenue or cost shares from periods t and t-1. Consequently, they take both periods into account. This is a distinct advantage over the fixed factor shares of the Laspeyres, Paasche and geometric indexes.

2.5.5 Other Superlative Indexes

The Törnqvist-Theil index is not the only *superlative* index with attractive properties. Fisher's ideal index is also a *superlative* index, and is *exact* for a "quadratic

---

[17] The derivation of revenue and cost shares requires the use of Shepard's lemma and the assumption of profit maximizing behaviour, an assumption which then is implicit in the Divisia index.

mean of order two" production function (Diewert, 1987). Although the Fisher index performs more strongly in the axiomatic sense, there are few outstanding theoretical economic reasons to choose Fisher indexing over Törnqvist-Theil.[18] In any event, Diewert (1987) points out that all *superlative* indexes should closely approximate one another if they are chained. The Törnqvist-Theil indexing procedure is implicitly a chained approach, and the Fischer index can easily be chained. Empirically, Fantino and Veeman's (1997) study of TFP in Canada supports Diewert's claim. The difference between the Törnqvist-Theil and chained Fischer index was indeed very small, while there was a substantial difference between the unchained Fisher and Törnqvist-Theil indexes.

2.6 Issues Concerning TFP Measurement and Index Number Procedures

Based on the preceding discussion, the Törnqvist-Theil indexing procedure can be considered an effective approach to TFP measurement. However, there are a number of potential pitfalls in measuring TFP that should be addressed. Some are specific to Törnqvist-Theil indexes, while others apply generally to the index number approach to TFP measurement.

2.6.1 Data Issues

The major shortcoming of the Törnqvist-Theil indexing procedure is that it requires both prices and quantities for each period. However, chained versions of the Laspeyres, Paasche and Fisher indexes also require this information. Therefore, if the data are available it is conceptually appropriate to use a *superlative* indexing procedure, such as the Törnqvist-Theil. In developing nations, limitations in the data may preclude the use of the Törnqvist-Theil or other chained indexes, and in this case other indexing methods or econometric estimation need to be used.[19] In the case of Prairie agriculture, however, the quality of data is generally excellent and using Törnqvist-Theil indexing to measure TFP is appropriate.

---

[18] Salami (1996) does point out that the Fisher index behaves better than the Törnqvist-Theil when some quantities are zero.

[19] Salami (1996) points out that by using an implicit Törnqvist-Theil index some of problems caused by data limitations can be mitigated.

2.6.2 Limiting Assumptions

A second limitation centers on two assumptions that are implicit in the growth accounting approach. The first results from the derivation of *exact* index number procedures. The derivation assumes perfectly competitive behaviour, as mentioned earlier. Of course, this is not the case in reality. One can argue that in some industries competitive behaviour is the exception, and monopolistic and/or monopsonistic behaviour the norm. However, in this regard, it is worth keeping in mind Varian's (1992) position: the key point is what insight into actual markets is generated by the assumption of perfect competition, not the assumption's approximation of reality. The second troublesome assumption follows from the independent calculation of input and output indexes. Christensen (1975) points out that this implicitly assumes separability between inputs and outputs, as is the case in the econometric approach. The implication is that the changing magnitudes of different outputs will not affect the efficient allocation of inputs (and vice versa). Like competitive behaviour, input-output separability is often an unrealistic assumption. Despite these two assumptions, the effectiveness of using the exact index number approach appears to outweigh its limitations. However, the underlying assumptions of competitive behaviour and input-output separability should serve as a caveat when measuring TFP in sectors marked by significantly different behaviour.

2.6.3 Bias in TFP Measurement

A further issue, which Murgai (2001) addresses in a study of the Green Revolution in the Indian Punjab, is the assumption of Hicks-neutral technical change in TFP measurement. Murgai shows that conventional growth accounting using the Törnqvist-Theil indexing procedure can understate TFP growth quite severely, when assuming Hicks-neutral technical change (i.e. when assuming that factor shares are invariant to technical change). During the Green Revolution Murgai found that TFP growth should have been some 100-200% higher per year than was estimated using the conventional growth accounting approach. Murgai established that technical change was land and labour saving, i.e. the crop varieties developed during the Green Revolution were biased towards water and fertilizer use. Consequently, much of the output growth attributed to increases in inputs was effectively the result of factor biased technical change, and should have been attributed to TFP growth. This illustrates the importance of determining whether factor biased technical change is present, and if it is, correcting TFP measurements accordingly.[20]

2.6.4 Aggregation Problems

Two additional issues which can be referred to as classical aggregation problems should also be addressed. Both have implications for TFP measurement. The first is accounting for changes in quality. Laspeyres and Paasche quantity indexes are particularly prone to this problem, since they use base or end period prices in weighting. Thus, they do not account for price increases that reflect increasing input quality. Chaining the indexes can mitigate this bias, and Törnqvist-Theil indexes account for changing prices in this regard.[21] However, indexes only account for quality changes as reflected in the inputs' prices (Rosegrant and Evenson, 1992). In many cases, the increased quality of an input is characterized by decreasing or constant input costs, e.g. human labour or computers. Thirtle and Bottomley (1992) point out that failure to account for the improved quality of inputs will lead to an overstatement of TFP.

The second issue is the durable goods problem, which is largely a technical issue, and is a perennial concern for accountants and economists. The difficulty is that there is no clear consensus on a protocol for attributing the flow of inputs (services) received from, and payments for, durable goods (Diewert and Nakamura, 2003). What quantity of services should be assigned to a specific period, and how should depreciation be handled? Assigning payments for durable goods to different periods is no easier, and is further complicated by interest payments. Even determining the share of a durable good's flow of services to attribute to a specific production process, is difficult.

[20] Bailey *et al* (2004) present a methodology using a latent variable approach where inaccurate TFP measurement due to biased technical change can be corrected.
[21] A similar analysis applies to outputs of the production process and decreases in the quality of goods.

2.7 Conclusion and Assessment of TFP and Törnqvist-Theil Indexing

The growth accounting or index number approach is not a panacea for TFP measurement. However, by using a *superlative* indexing procedure, such as the Törnqvist-Theil and being aware its potential shortcomings, the index number approach can serve as an attractive alternative to econometric methods of TFP measurement. Rather than bias the aggregation of data by using a large number of restrictive and perhaps untenable assumptions, Törnqvist-Theil indexing procedures let the data speak for themselves. A more accurate measure of TFP has intrinsic value, but it also forms a superior basis for undertaking further study and evaluating policy options.

In terms of further study, TFP measures can be disaggregated to calculate the sources of productivity growth, be they returns to scale, degree of technical efficiency, or technological progress (see Section 3.1). Econometric analysis can also be conducted to estimate the determinants of productivity growth, e.g. research and development expenditures (see Chapter 7). However, if the original measurement of TFP is significantly flawed, then any further studies will also be subject to error. The implication is that viable policy options may not be suggested and misguided policy may be adopted, as a response to inaccurate productivity growth estimates.

The preceding discussion indicates that measuring total factor productivity using Törnqvist-Theil indexing is an appropriate methodology to use in this study in order to obtain accurate estimates of productivity growth in Prairie agriculture.

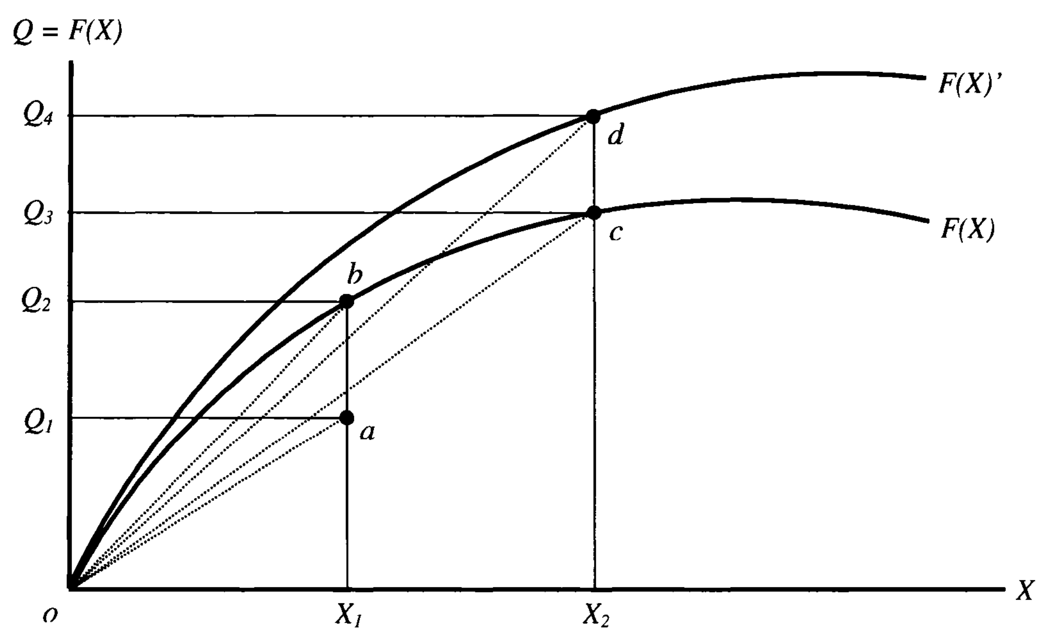
CHAPTER 3: PRODUCTIVITY DECOMPOSITION AND PRODUCTION STRUCTURE METHODOLOGY

In Chapter 2 the conceptual rationale motivating the use of TFP and Törnqvist-Theil indexing as a measure of productivity was demonstrated. Regrettably, the resulting TFP estimates do not shed much light on how or why productivity growth occurs. The focus of this Chapter is on describing the neoclassical theory of the firm and related economic modeling that permits deeper inquiry into how the measured productivity growth occurs.

3.1 Productivity Decomposition: Conceptually

Our understanding of productivity growth is enhanced by decomposing productivity growth into its three component parts: technical change, scale effects, and changes in the degree of technical efficiency. The components of productivity can be illustrated graphically following Capalbo (1988).

Figure 3.1 Productivity and its Components



3.1.1 Technical Efficiency

Figure 3.1 shows an arbitrary production technology *F(X)* that transforms inputs (*X*) into output (*Q*).[1] With technology *F(X)* using X_1 inputs, and assuming technically efficiency, production will occur on the production frontier at point *b* resulting in an output of Q_2. Production at point *a* is technically inefficient and produces only Q_1 output. Intuitively it is clear that production at point *b* is more productive than at point *a*, since more output is being produced with the same amount of inputs. Another way of looking at this is that production at point *b* requires, on average, less inputs per unit of output than at point *a*; or, alternatively, the slope of line segment *ob* is steeper than *oa*. Formally:

$$\frac{X_1}{Q_2} < \frac{X_1}{Q_1} \qquad \text{and} \qquad \Delta ob > \Delta oa$$

A movement from point *a* to point *b* represents an improvement in the degree of technical efficiency and hence productivity. Improvements in technical efficiency are an indication of improvement in the management of existing resources (elimination of input waste given the current state of technology); in other words, improvements in technical efficiency are indicative of a movement towards best practice, in terms of production input usage, at a particular point in time.

3.1.2 Scale Effects

Another component of productivity is scale effects. If production using technology *F(X)* was expanded from point *b*, using X_1 inputs, to point *c*, using X_2 inputs, then output would be increased from Q_2 to Q_3. However, due to the decreasing returns to scale characterization (in Figure 3.1) of the production technology over this input range, output will increase proportionately less than inputs. In this case, the impact of scale is to decrease productivity, since:

---

[1] The shape of production technologies *F(X)* and *F(X)'* in Figure 3.1 is chosen on the basis of its utility as a pedagogical tool rather than as an approximation of actual production relationships in Prairie agriculture. For instance, both production technologies depicted in Figure 3.1 show decreasing returns to scale. In reality, increasing returns to scale are a more likely characterization of Prairie agriculture following Veeman *et al's* (1995) study of Prairie agriculture and Griliches' (1963 & 1992) findings for U.S. agriculture.

$$\frac{X_2}{Q_3} > \frac{X_1}{Q_2} \qquad \text{and} \qquad \Delta oc < \Delta ob$$

Scale effects point to certain ranges of input use that are innately more productive in the production of outputs due to economies of scale inherent in the production process.

3.1.3 Technical Change

The third component of productivity is technical change, which encompasses innovation or the adoption of new technology. Technological innovation would cause the entire production technology to shift upwards from *F(X)* to *F(X)'*. Thus, by using X_2 inputs it becomes possible to produce at point *d*, with Q_4 output, rather than at point *c* with Q_3 output. Technical change then, in this case, increases productivity, since:

$$\frac{X_2}{Q_4} < \frac{X_2}{Q_3} \qquad \text{and} \qquad \Delta od > \Delta oc$$

Technical change, typically viewed as the largest component of productivity growth, can be understood as technological advance in its broadest sense. It is not just updated machinery and equipment, but encompasses technological advances in all inputs, ranging from novel ways of using resources (e.g. improved organization) to superior inputs (e.g. improved crop and livestock genetics).

3.1.4 Multiple Effects

The preceding examples are straightforward since they deal with only one component of productivity at a time, and in a two dimensional context. Typically, all three components of productivity occur simultaneously in *n*-dimensions (multiple outputs and multiple inputs). The challenge is to identify the role each plays in productivity growth. In the case of the arbitrary production technologies presented in Figure 3.1, the three components of productivity have dissimilar impacts on productivity growth and work in opposite directions. If production in period *t* occurs at point *a* and at point *d* in period *t+1* there is an increase in productivity since the slope of *od* > *oa*. However, when the productivity growth is decomposed, it is clear that although increases in technical efficiency and technical change advance productivity, the scale effects serve to retard productivity growth (even though the net result is positive productivity growth).[2]

3.1.5 Assumption of Technical Efficiency

Section 3.1 indicates that productivity can be decomposed into three components. Nonetheless, throughout this study, technical efficiency is assumed, and only technical change and scale effects are directly assessed.[3] Although this may appear to be a relatively strong assumption there are a number of compelling reasons to impose the assumption of technical efficiency.

First, conceptually, the assumption of technical efficiency permits the focus of the study to rest on the impacts of scale and technical change, which are anticipated to be the dominant components of long run productivity growth. Second, empirically, this assumption permits the use of aggregate time series data at a provincial level. In order to assess the effect of changes in the degree of technical efficiency cross-sectional or panel data (typically at the firm level) would need to be employed (see Fan (1991), for an example of a three way decomposition of agricultural productivity growth in China using panel data). Third, at the aggregate level of analysis and over a long time period the assumption of technical efficiency may not be so unrealistic. Over time if the degree of technical efficiency is constant or changes only marginally it would exhibit only a limited influence on productivity growth. While the technical efficiency of individual firms may be expected to vary substantially over time it is not clear that the technical efficiency of

---

[2] It is also apparent that if the production technology is depicted as exhibiting constant returns to scale (a linear production technology) then the scale effect is removed and productivity is composed solely of technical change and improvements in technical efficiency. If technical efficiency and a constant returns to scale production technology are assumed, then productivity is analogous to technical change.

[3] Allocative efficiency for a given level of output is also assumed, since it is assumed that firms and the livestock and crop sectors of each province are cost minimizers. While technical efficiency indicates that a physically efficient mix of inputs is used to produce a given level of output, allocative efficiency indicates that a cost minimizing input combination, given input prices, is being used to produce a given level of output. Technical and allocative efficiency, together, form the necessary and sufficient conditions for economic efficiency; hence, economic efficiency for a given level of output is also being assumed in this study (see Yotopoulos and Nugent (1976) for a detailed discussion of technical, allocative and economic efficiency).

an aggregation of firms would show much variability. Finally, the significance of a measure of technical efficiency at the aggregate level of analysis is questionable. Can an economic sector of an entire province with its own unique economic, social and political characteristics be meaningfully assessed as technically efficient or inefficient relative to another economic entity?

3.2 Productivity Decomposition: Algebraically

Section 3.1 illustrated productivity decomposition conceptually. It is also possible, using neoclassical production theory, to decompose productivity algebraically. Empirically then, TFP estimates obtained using the index number approach detailed in Chapter 2 can be decomposed. This is essential, since only under some very restrictive conditions does the index number approach provide an accurate account of the components of the productivity growth; it assumes that measured TFP is analogous to technical change.[4] By employing neoclassical production theory many of the limiting assumptions associated with the index number measure of TFP can be relaxed, and TFP can be decomposed into three parts: non-constant scale effects, technical change, and a residual that accounts for measurement error and any other factors not subsumed under the first two components.[5] It should be pointed out that to the extent changes in the degree technical efficiency are a component of productivity growth they will appear in the residual. Formally the decomposition can be illustrated. First, recall from Section 2.5.4 that the proportionate rate of TFP growth was shown as:

$$(2.3) \quad \dot{TFP} = \dot{Q} - \dot{X}$$

---

[4] Under limiting assumptions, such as technical efficiency, a constant returns to scale production technology and Hicks-neutral technical change, the index number measure of TFP is equivalent to technical change.
[5] Developing a more realistic portrayal of productivity growth is more than a matter of theoretical interest. The composition of productivity growth has policy implications. Productivity growth driven largely by economies of scale should prompt a significantly different policy response than productivity growth induced by technical change.

where (using a Divisia index),

$$(2.4)\quad \dot{Q} = \sum_{j=1}^{m} \frac{p_j q_j}{R} \dot{q}_j$$

$$(2.5)\quad \dot{X} = \sum_{i=1}^{n} \frac{w_i x_i}{C} \dot{x}_i$$

This measure of TFP growth can be related to an aggregate cost function, and then decomposed into shifts in the cost function, signifying technical change, and non-constant scale effects. Following Capalbo (1988), and assuming an aggregate cost function $C = g(w_i,\ldots,w_n,Q,t)$, the relationship between TFP growth and the aggregate cost function can be written as follows:

First, differentiating the cost function with respect to time yields:

$$(3.1)\quad \frac{\partial C}{\partial t} = \sum_{i=1}^{n} \frac{\partial g}{\partial w_i} \frac{\partial w_i}{\partial t} + \frac{\partial g}{\partial Q} \frac{\partial Q}{\partial t} + \frac{\partial g}{\partial t}$$

and dividing through by C and employing Shephard's lemma yields:

$$\frac{1}{C} \frac{dC}{dt} = \sum_{i=1}^{n} \frac{x_i}{C} \frac{\partial w_i}{\partial t} \frac{w_i}{w_i} + \frac{1}{C} \frac{\partial g}{\partial Q} \frac{\partial Q}{\partial t} \frac{Q}{Q} + \frac{1}{C} \frac{\partial g}{\partial t}$$

simplifying yields,

$$\dot{C} = \sum_{i=1}^{n} \frac{w_i x_i}{C} \dot{w}_i + \left(\frac{Q}{C} \cdot \frac{\partial g}{\partial Q} \right) \dot{Q} + \dot{B}$$

which can be rewritten as:

$$(3.2)\quad \dot{B} = \dot{C} - \sum_{i=1}^{n} \frac{w_i x_i}{C} \dot{w}_i - \varepsilon_{CQ} \dot{Q}$$

where ε_{CQ} is the cost-output elasticity, and $\dot{B}$ is the proportionate shift in the cost function which can be decomposed into the change in cost, minus the change in aggregate inputs, minus the scale effect.[6] Capalbo (1988) shows that the proportionate

---

[6] Chambers (1988) and others refer to the cost-output elasticity as cost flexibility, since it is a ratio of marginal to average cost. Cost-output elasticity (or some variant of it) appears to be the more popular terminology, and will be used throughout the study.

shift in the cost function can be related to the TFP growth, as defined in equation (2.3), as follows:

First, differentiating the cost equation, $C = \sum_{i=1}^{n} w_i x_i$, with respect to time, and dividing through by C yields:

$$(3.3) \quad \dot{C} = \sum_{i=1}^{n} \frac{w_i x_i}{C} \dot{w}_i + \sum_{i=1}^{n} \frac{w_i x_i}{C} \dot{x}_i$$

Substituting (3.2) into (3.3) yields:

$$(3.4) \quad \dot{B} = \sum_{i=1}^{n} \frac{w_i x_i}{C} \dot{x}_i - \varepsilon_{CQ} \dot{Q}$$

Equation (3.4) can be rewritten using equation (2.5) as:

$$(3.5) \quad \dot{X} = \varepsilon_{CQ} \dot{Q} + \dot{B}$$

Finally, substituting (3.5) into (2.3) yields the following relationship between TFP growth and the shift in the cost function:

$$(3.6) \quad \dot{TFP} = -\dot{B} + (1 - \varepsilon_{CQ}) \dot{Q}$$

TFP growth is analogous to technical change as measured by a shift in the cost function only when $\varepsilon_{CQ} = 1$, i.e. cost-output elasticity is unity (constant returns to scale).[7] When $\varepsilon_{CQ} \neq 1$ TFP growth is composed of technical change ($-\dot{B}$) and non-constant scale effects ($(1 - \varepsilon_{CQ})\dot{Q}$). The relationship expressed in equation (3.6) can also be adjusted to account for the case of multiple outputs. Bailey and Freidlaender (1982) show that for a multi-output cost function the overall returns to scale (S), which is simply the reciprocal of the cost-output elasticity, can be written as:

$$(3.7) \quad S = \frac{C}{\sum_{j=1}^{n} Q_j \cdot MC_j} = \frac{C}{\sum_{j=1}^{n} Q_j \cdot \frac{\partial C}{\partial Q_j}} = \left[\sum_{j=1}^{n} \varepsilon_{CQ_j} \right]^{-1}$$

[7] In addition, as pointed out in Section 3.1.4, technical efficiency is also assumed.

where MC_j is the marginal cost for the j^{th} output. It follows that the overall cost-output elasticity for a multi-output cost function is simply the sum of each output's cost-output elasticity. Equation (3.7) can then be written as follows for the multi-output case:

$$(3.8) \quad \dot{TFP} = -\dot{B} + (1 - \sum_{j=1}^{n} \varepsilon_{CQ_j})\dot{Q} \qquad \text{for } j = 1 \ldots n$$

By using equation (3.6) in the single output case or (3.8) in the multi-output case, TFP as measured using an index number methodology can be decomposed into a non-constant scale effect and technical change. Estimates of the cost-output elasticity (ε_{CQ_j}) and the shift of the cost function ($-\dot{B}$) can be obtained econometrically and using the Törnqvist-Theil discrete approximation to the Divisia index the proportionate growth rate of outputs ($\dot{Q}$) can be calculated ensuring that equations (3.6) and (3.8) are empirically tractable.

3.3 Modeling Prairie Agriculture

A great deal of insight into the nature of productivity growth can be obtained by modeling the production structure of Prairie agriculture. The act of modeling, however, by its very nature, involves placing restrictions on the conclusions that can be derived from the data. The restrictions arise from the economic theory imposed to gain insight into the economic phenomena under consideration. Nevertheless, it is preferable, to the extent possible, to let the data speak for themselves - in this vein, the fewer the restrictions the better.

3.3.1 Translog Cost Function Conceptually

Over the past thirty years the use of flexible functional forms in modeling in production economics has become commonplace. The rationale for using a flexible functional form is that it limits the number of *a priori* assumptions imposed on the industry or firm structure being analyzed. The particular flexible functional form used in this study is the translog. There are three key reasons for using it: first, it limits the restrictions placed on the data (e.g. constant elasticities of substitution or constant returns to scale); second, it is the most commonly used flexible functional form, consequently there is substantial body of empirical and theoretical work regarding its properties and interpretation; third, to ensure theoretical consistency with Törnqvist-Theil index number procedures, the use of a translog functional form is required in the decomposition of the TFP estimates.[8]

Beyond the choice of appropriate functional form there are a number of approaches that can be used to model the industry's production structure. The most obvious method is to use a production function to model the production technology directly. However, through the use of duality concepts the salient characteristics of the underlying production technology can be derived from the cost function without modeling the production technology directly. The cost function approach assumes only cost minimizing behaviour on the part of producers, a less restrictive assumption than the assumption of profit maximization required when using a profit function.[9] Another distinct advantage of the cost function approach is that it takes output quantities and input prices as exogenous. In the case of Prairie agriculture, the structure of the industry suggests that this is a reasonable assumption, as is the assumption of cost minimization. In contrast, the production function approach takes output and input quantities as exogenous. Although output may be assumed to be exogenous, inputs would be expected to be endogenous.[10]

3.3.2 Disaggregation of Agriculture: Crops and Livestock Activities

Prior to presenting the formal models or describing the data in detail it is necessary to substantiate the separation of aggregate Prairie agricultural production into crops and livestock activities. The primary reason to divide aggregate agriculture into the two activities is in order to facilitate comparisons between them. There is also a strong theoretical basis for the disaggregation. As Huffman and Evenson (1993) point out there are substantial differences inherent in the production processes involved in either activity. At a basic level, the biological processes involved in the production of livestock and crops are obviously very different. In addition, many of the inputs used in the production

---

[8] Alternatively, if Fisher's ideal index was used to measure TFP, instead of the Törnqvist-Theil index, then, to maintain theoretical consistency, since this index is *exact* for a quadratic mean of order two production function, a quadratic flexible functional form would be used in the decomposition (Diewert, 1987).

[9] Cost minimization is a necessary but not sufficient condition for profit maximization.

[10] Revenue functions, another indirect approach, also assume that input quantities are exogenous - an unrealistic portrayal of Prairie agriculture.

of either output are distinct; for example, crop outputs are an input to livestock, but livestock is not generally an input to crops. Thus, on a conceptual basis it is questionable whether it is appropriate to model the two distinctive production processes under the rubric of aggregate agriculture, particularly if it is possible to successfully disaggregate the data.

However, the foregoing case for the disaggregation of the data should not minimize the theoretical challenges that remain, since there is significant interconnectedness between crops and livestock activities.[11] Firstly, some output from crops production is an input to the livestock production in the form of feed. Second, many farms produce both livestock and crops. The analysis conducted in this study relies on the somewhat artificial division of farming into either strictly crops or livestock activities; what in reality is often a blurry boundary is rendered sharp in this investigation. Finally, the argument can also be made that, particularly with regard to livestock, different output subtypes require substantially different production processes. A good example, in this regard, could be found in comparing the production processes involved in poultry as compared to beef production. Nonetheless, this is an argument for more disaggregation, rather than less. The premise of this study is that the production processes involved in poultry and beef, for example, are not as fundamentally different as grain production is in comparison to poultry and beef production.

3.3.3 Single and Multi-Output Models Conceptually

As illustrated in equations (3.7) and (3.9) the index number estimates of TFP can be decomposed using either multi-output or single output cost functions. A multi-output cost function with crops and livestock specified as its two outputs can be used to decompose the provincial and Prairie level agricultural TFP growth rates. Although important information can be obtained using a multi-output cost function approach, it is also limited in a number of important respects.

A multi-output cost function is appropriate for firm level analysis where a firm with a specific cost structure produces multiple outputs. At the firm level it makes little

---

[11] The empirical challenges of disaggregating the aggregate agriculture into crop and livestock activities are covered in greater detail in Chapter 4.

sense to disaggregate the data and conduct the analysis with a separate cost functions for each output. Firstly, disaggregation of the data may be difficult or undesirable. Secondly, a series of single output cost functions will not relate essential information regarding the production structure that is specific to firms producing multiple outputs, particularly the presence of economies or diseconomies of scope. Economies of scope indicate that a single firm can produce multiple outputs at a lower cost than can multiple firms each specializing in the production of a specific output. Bailey and Friedlaender (1982) point out a number of reasons for the existence of economies of scope such as: the sharing of fixed factors of production; the reuse of inputs in the production of multiple outputs; and technology and production processes that are more efficient when geared towards the production of multiple outputs.

With aggregate level data (as is the case in this study), using a multi-output approach becomes somewhat problematic. First, assuming that both the crops and livestock sectors can be accurately represented using the same cost function is a tenuous assumption for activities characterized by considerably different production processes. Accordingly, activity specific cost functions appear to offer a more realistic model of production at the aggregate level.[12] Second, although empirically somewhat challenging to carry out, as illustrated in Chapter 4, Agricultural Census data from Statistics Canada permits the disaggregation of data between crops and livestock activities. Moreover, there does not appear to be a compelling theoretical reason (at an aggregate level) to suggest that the data should not be divided between crops and livestock activities. Third, a key advantage of using a separate cost function for each activity is that it permits the decomposition of activity specific TFP measures, which should yield deeper insight into the divergent productivity growth occurring in the crops and livestock sectors.

Unfortunately, single-output cost functions do not provide a measure of economies of scope. Economies or diseconomies of scope in the aggregate sense are conceptually different than at the firm level, but it seems likely that they would be present to some extent. For example, shared provincial infrastructure between the crops and

---

[12] In addition to fundamentally different production processes, the substantial divergence in productivity growth rates found by Huffman and Evenson (1993) and Veeman *et al* (1997) suggest that significant differences between the crops and livestock sectors exist.

livestock sectors could result in economies of scope at the aggregate level. Conversely, the existence of both crops and livestock activities might reduce the level of specialization in a specific agricultural activity and result in diseconomies of scope. The estimation of a multi-output cost function provides information in this regard. The multi-output cost function also serves as a means to corroborate the results of the analysis by activity, since the results of the individual single output crops and livestock cost functions should not be expected to diverge greatly from those of the aggregate multi-output cost function. For the sake of comprehensiveness both single and multi-output cost functions are used in this study.[13]

3.4 Interpretations: Aggregate and Firm Level Analysis

A final point should be made concerning the interpretation of findings in this study. The analysis in this study takes place at an aggregate level; accordingly the interpretation of any results relates to Prairie or provincial level agriculture and their crops and livestock components. Firm level interpretations of the results can generate erroneous conclusions. This is the case when (dis)economies of scale and scope are considered.

3.4.1 Economies of Scale and Scope

A finding of economies of scale at the firm level suggests that an individual producer could take advantage of declining average cost by increasing their size and expanding their output. However, at the aggregate level of analysis this finding implies only that the crops or livestock agriculture in aggregate can take advantage of increasing returns to scale by expanding their aggregate output, and offers ambiguous insight regarding optimal firm behaviour and size.[14] The interpretation of economies of scope is also specific to aggregate analysis. At the firm level, economies of scope signify that a single firm can produce both outputs (crops and livestock) cheaper than two separate

---

[13] Single and multi-output approaches to production are shown schematically in Appendix A.

[14] This is the case, since aggregate output depends on both the size of the average firm and the number of firms. For instance, a number of new firms could enter the marketplace and actually reduce average firm size, while increasing aggregate output.

firms specializing in crops and livestock production respectively. At the aggregate level, economies of scope indicate that a province can produce both outputs cheaper than two separate specialized provinces. The aggregate measure provides no indication of whether the provincial economy is characterized predominantly by firms exhibiting economies or diseconomies of scope.

Although interpretation at the aggregate level is less straightforward conceptually than at the firm level, it is not a question of the relevance of the aggregate measures. The conclusions reached can serve to inform provincial or national policy in an aggregate context, a capacity not fully realized through firm level analysis. The conclusions obtained at the aggregate level may not correspond to those attained through firm level analysis, and from this standpoint, the aggregate level methodology provides a valuable counterpart to analysis focusing exclusively on firm level production.

3.5 Biased Technical Change

A final measure that needs to be considered in the analysis of productivity growth is the bias of technical change. Section 2.6.3 related that biased technical change can lead to understated productivity growth; in addition to its primary role of shifting the production frontier outward, technical change is also responsible for increasing the accumulation of particular inputs relative to other inputs. For example, in Canadian agriculture it is commonly held that technical change is biased towards capital accumulation (Karagiannis and Furtan, 1993; Adamowicz, 1986). That is, capital has advanced technologically over time (shift in the production function) and agriculture has become more capital intensive (factor bias, or input accumulation).

Deriving the bias of technical change from the econometric models is straightforward and provides important empirical information. The bias of technical change reveals the inputs related to technical change, permitting an improved understanding of the nature of technical change in terms of its role in the accumulation of increasingly productive factors of production. This is an important step in reaching accurate conclusions regarding agricultural productivity growth, of which technical change is regarded as being the dominant component (Capalbo, 1988; Huffman and Evenson, 1993).

CHAPTER 4: DATA

4.1 Introduction

The analysis of productivity growth in this study requires an accounting of the inputs and outputs of Prairie agriculture. Consequently, the accuracy of the results depends to a great extent on the data described in this Chapter, and the methodology used in constructing the data. Descriptive information regarding the data are also presented, since an overview of Prairie agriculture and trends in input and output usage over the sixty-five year period of the study are essential in assessing the productivity growth that has occurred.

The data used in this study are a refinement and expansion of a data set originally constructed by Shiferaw Adilu and Alberto Fantino using data from Alberta Agriculture Food and Rural Development and Statistics Canada.[1] Much of their methodology has been retained, specifically as it relates to the allocation of inputs between crops and livestock agriculture (explored in Section 4.3.2).[2]

4.2 Livestock and Crop Outputs

The allocation of outputs between crops and livestock activities is straightforward, and does not involve the complications inherent in the attribution of inputs between the two activities. However it is instructive to review the individual outputs comprising the livestock and crop outputs in each province. Although the livestock output types have remained constant over the 1940-2004 period, the crops

---

[1] Adilu and Fantino are former Research Associates with the Department of Rural Economy, University of Alberta. The original data arose out of a number of Alberta Agricultural Research Institute Projects under the direction of Terrence Veeman.
[2] Unless otherwise noted the input and output data used in this study were obtained from Statistics Canada and the provincial departments of agriculture. Any aggregation of inputs or outputs was performed using Törnqvist-Theil indexing procedures. The input and output relationships for aggregate agriculture, and the individual crop and livestock activities are shown in Appendix A. The actual input and output data used in the analysis are reported in Appendix B.

outputs have changed through the introduction of new crops, such as canola in the1950s, and the increased production of a variety of specialty crops over the past twenty years. Not all agricultural output is considered. Most notable is the absence of horticulture, and a number of the smaller specialty crops (e.g. safflower), and specialty livestock (e.g. bison). Table 4.1 indicates that, on the basis of cash receipts, the vast majority of output has been included. It can be observed that a lower percentage of cash receipts are considered in Alberta and Manitoba's crop sectors in 1990 and 2000. This finding reflects the growth over time of specialty agriculture (principally involving floriculture, nursery and vegetable production) in these two provinces.

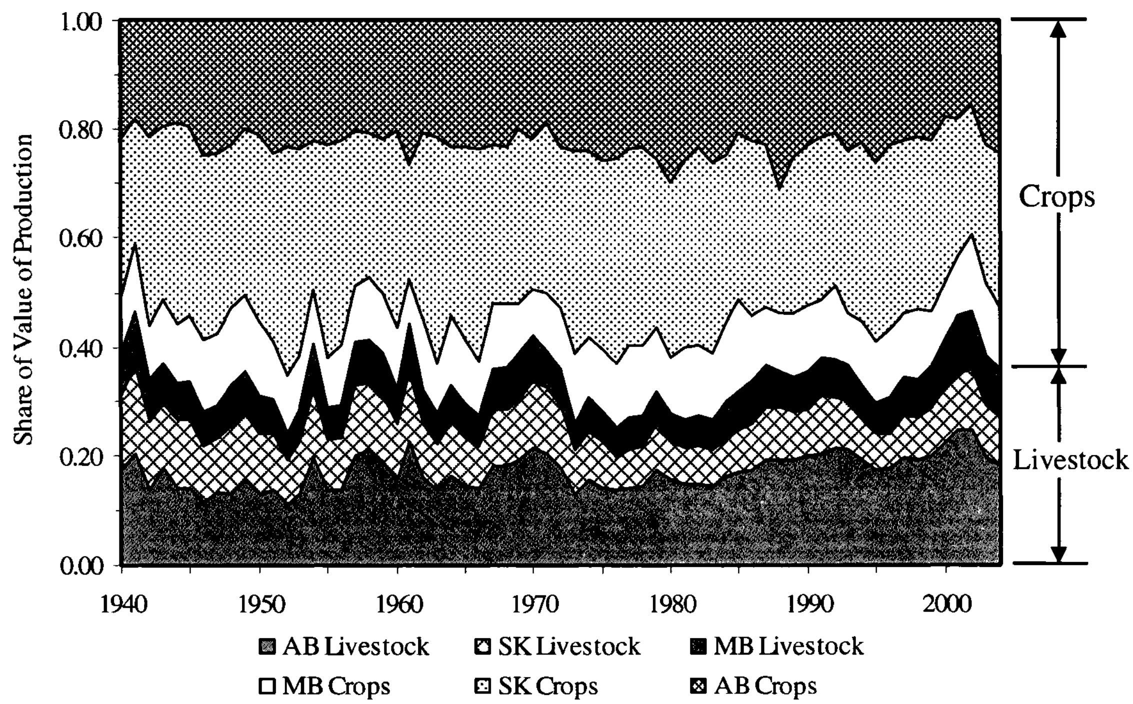
Table 4.1 Cash Receipts of Crops and Livestock as Percentage of Total Sectoral Cash Receipts

		1940	1950	1960	1970	1980	1990	2000
Alberta	Crops	96.7	94.5	95.2	93.5	95.4	90.2	88.9
	Livestock	95.0	97.3	97.9	98.3	98.3	98.0	96.4
Sask.	Crops	97.8	98.6	99.0	98.3	99.1	98.0	95.3
	Livestock	94.1	98.0	98.1	98.6	98.0	97.2	94.2
Manitoba	Crops	94.3	95.1	95.8	91.4	94.3	91.2	89.9
	Livestock	94.1	95.4	95.3	98.4	96.7	94.8	94.1

An overall sense of the respective shares of crops and livestock in Prairie agriculture, as well as each province's contributions, can be obtained by examining Figure 4.1. Crops make up the majority of the output. From 1940 to 2004, on average, crops comprise two thirds of the Prairies' total value of production. However, from 1980 onward, the share of livestock in output grows considerably. Over the final five years of the sample livestock's share of output is slightly over 41 percent. Saskatchewan's crops production is the largest of the Prairie provinces and dwarfs its livestock production. Alberta produces the largest share of livestock, and is responsible for slightly more livestock production than both Saskatchewan and Manitoba combined. The value of Alberta's crop production has traditionally been higher than the farm level value of its livestock production, yet over the last fifteen years this has become more of an even split, with the value of livestock production outpacing that of crops in a number of years. Manitoba's overall agricultural production is smaller than either Saskatchewan or Alberta, yet it is still substantial, and has reflected a relatively equal split between livestock and crops, with the livestock share growing over time.

The impacts of major events on Prairie agricultural production can also be seen in Figure 4.1. For example, the major droughts of 1961 and 2001/2002 are apparent as poor harvests in these years result in a decline in the relative share of crops in total Prairie agricultural production. The finding of a case of BSE in an Alberta cow and subsequent international trade restrictions on Canadian cattle are also visible. The relative share of livestock in total Prairie production declines in 2003 and more notably in 2004.

Figure 4.1 Livestock and Crops as Share of Total Value of Prairie Production by Province, 1940-2004



4.2.1 Livestock Outputs

For all three Prairie provinces the same six farm level livestock outputs are used: cattle and calves, swine, sheep and lamb, chicken and turkey, eggs, and dairy products.[3] Poultry are reported by weight, dairy by volume, eggs by number, and cattle and calves, swine, and sheep and lamb by number of head. In most cases, deriving the quantity and price of livestock is straightforward; they are reported in various Statistics Canada publications and by the provincial departments of agriculture. In the case of cattle and swine, however, the quantities require adjustment to reflect the increasing size of both cattle and swine over time. Indexes indicating the increased size of cattle and swine are constructed from USDA average slaughter weight data over the 1941 to 2004 time period.[4] Quantities are also adjusted to reflect inventory changes for cattle, swine and sheep; the quantity produced numbers used in the study reflect the changes in inventory, net live sales (interprovincially and internationally) and number slaughtered.[5] Price data are obtained by dividing cash receipts by live sales and slaughter, and total value of production is then calculated as the product of total quantity produced and price. Consequently, depending on the change in inventory and purchases of livestock, the value of production could be greater, less, or equal to cash receipts for any given year.

Figures 4.2, 4.3, 4.4 and 4.5 show the respective value of production shares of the different livestock output types for the Prairies and the individual provinces. Figure 4.2 indicates the rapidly increasing role cattle plays in Prairie livestock production from the 1940s to the 1970s, as it becomes the dominant livestock output. In contrast, poultry and dairy display a gradual relative decline over the entire period. The relative share of hog production declines rapidly in the 1940s, but remains fairly constant thereafter, until the mid-nineties when it begins to expand rapidly.

---

[3] For the sake of brevity, henceforth, the cattle and calves, and sheep and lamb output categories are referred to as cattle and sheep respectively, and poultry is understood to encompass chicken, turkey and eggs. In addition, the terms swine and hogs are used interchangeably throughout.

[4] The USDA data compared favourably with Canadian data on average slaughter weights obtained from CanFax over the more limited 1993 to 2004 period.

[5] The data used to derive total annual production of cattle and calves, swine, and sheep and lambs are from Statistics Canada's Cattle, Hog and Sheep Statistics publications.

The trends in livestock output at the Prairie level obscure substantial variability amongst the provinces. Figures 4.3 and 4.4 show that Saskatchewan and Alberta exhibit similar output structures; both provinces' livestock sectors are characterized by a rapid increase in the relative share of cattle production from 1940 to 1970, and a corresponding decline in the relative share of swine production. Figure 4.5 shows that Manitoba has a larger proportion of livestock output made up of poultry and dairy, and it is swine production that increases rapidly from the 1950s onward to become Manitoba's dominant livestock output, while cattle's relative share declines in significance.

Figure 4.2 Prairie Livestock Output: Value of Production Shares, 1940-2004

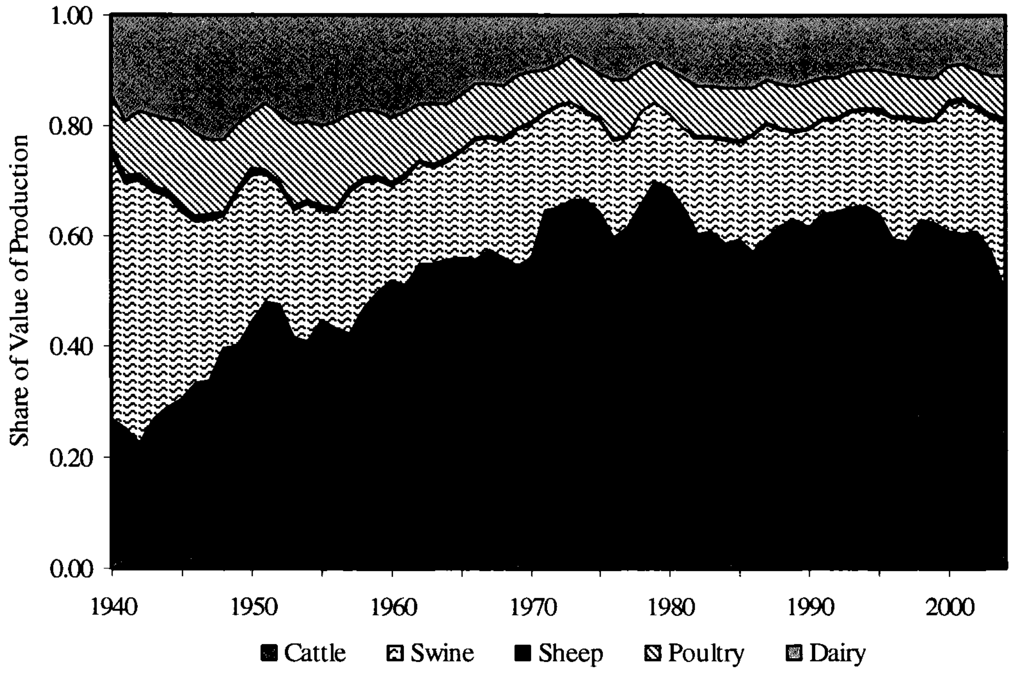


Figure 4.3 Alberta Livestock Output: Value of Production Shares, 1940-2004

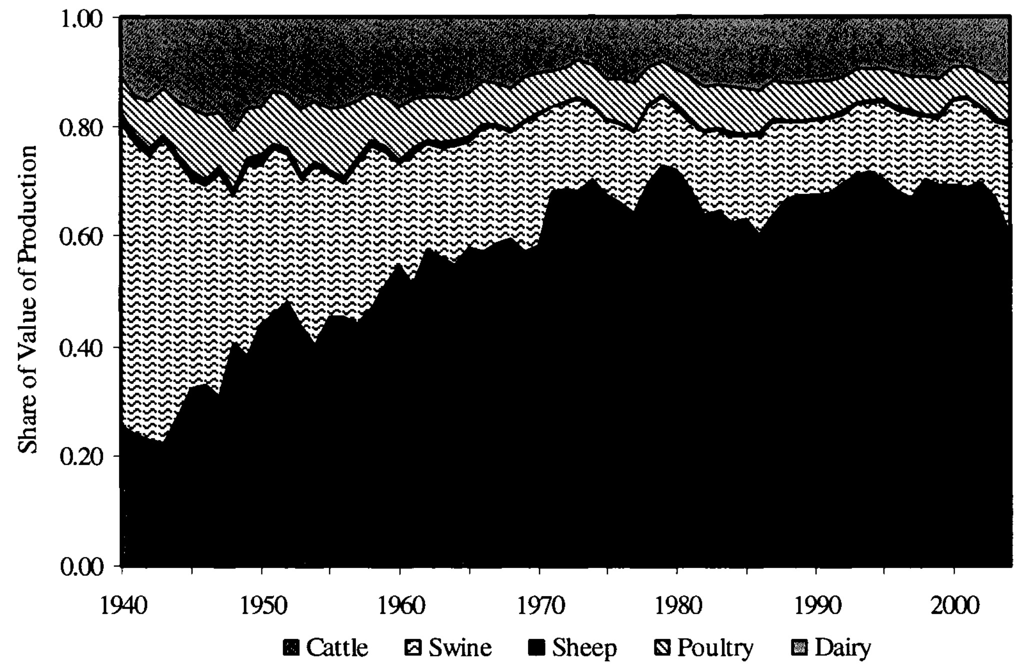


Figure 4.4 Saskatchewan Livestock Output: Value of Production Shares, 1940-2004

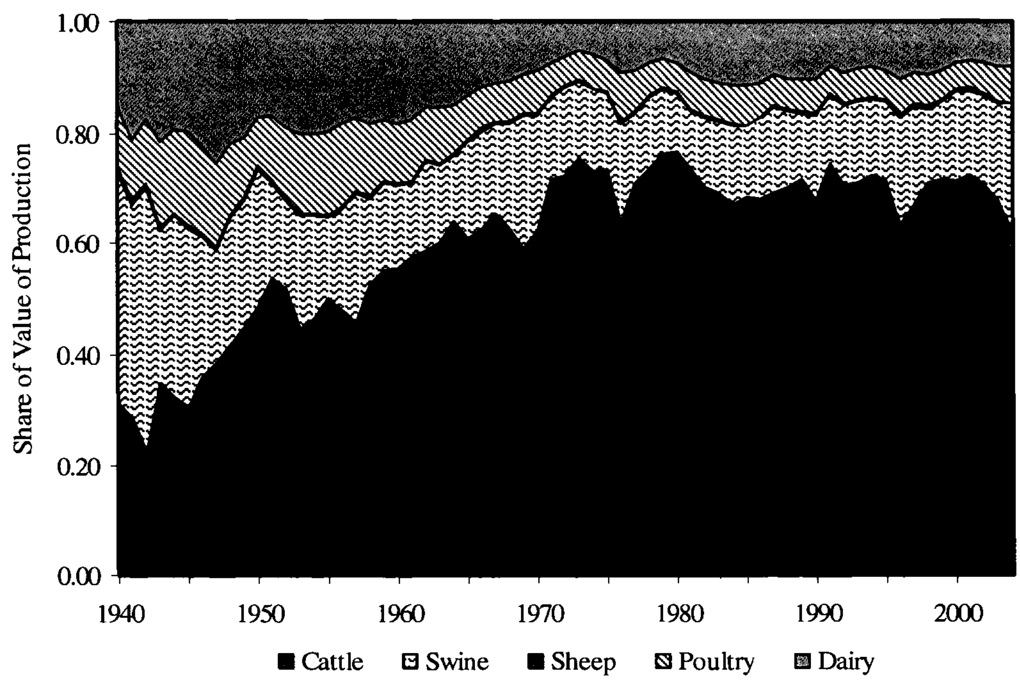
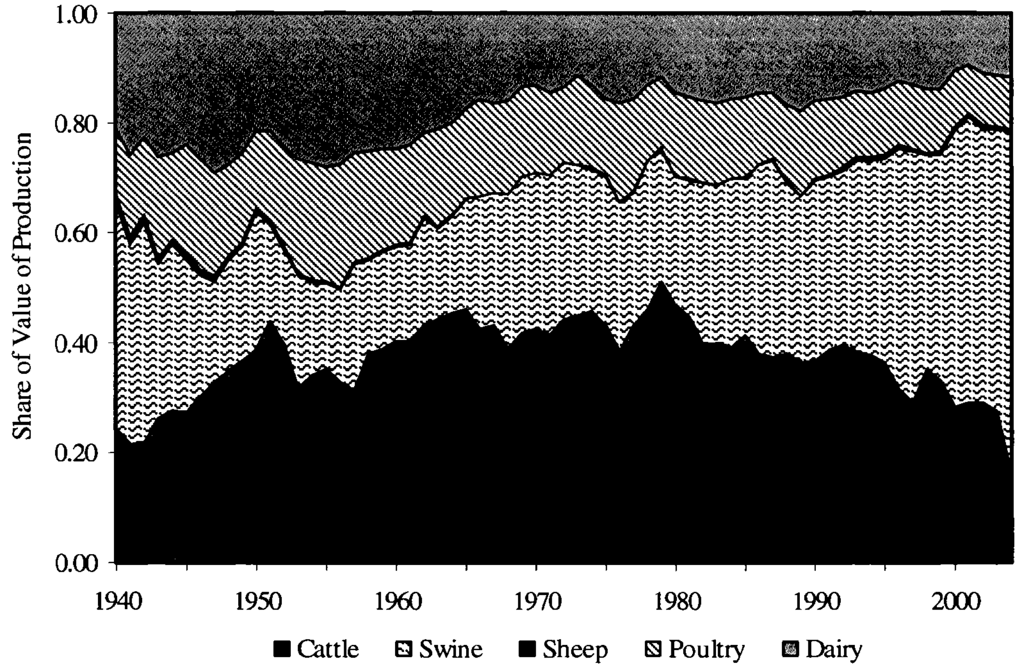


Figure 4.5 Manitoba Livestock Output: Value of Production Shares, 1940-2004



4.2.2 Crop Outputs

The number of crop outputs for each province and the Prairies have increased over time as new crops have been adopted. The majority of crop production by the Prairie provinces is made up of nine traditional crops; however, the role of specialty crops has increased over time. The traditional crops considered are: wheat, oats, barley, rye, mixed grains, flaxseed, mustard seed, tame hay and canola. In addition, for each province the following list of additional crop outputs (specialty crops) are considered: for Alberta, sugar beets, dry peas, dry beans and potatoes; for Saskatchewan, canary seed, dry peas and lentils; for Manitoba, sugar beets, dry peas, dry beans, potatoes, sunflower seeds and grain corn. The data relating to crop outputs and their prices are derived from various Statistics Canada publications and from the provincial departments of agriculture. The value of production is calculated as the product of total tonnage harvested and price. Consequently the value of production can be expected to differ from cash receipts due to the role that inventory adjustments, seed hold back, and crops used on farm for feed will have on cash receipts.

Figures 4.6, 4.7, 4.8 and 4.9 show the value of production shares of the different crop output types for the Prairies and the individual provinces. Figure 4.6 points to the relative decline in many of the traditional crops over time – particularly wheat, and the aggregate category of oats, rye, mixed grains, flaxseed and mustard seed. Barley and tame hay have increased their share largely due to their importance as livestock feed. The share of canola has grown rapidly from its introduction in the 1950s, as have specialty crops (dry peas and beans, lentils, sugar beets, sun flower and canary seed, grain corn, and potatoes), but at a lower rate. The impact of the 1970 Lower Inventories For Tomorrow (LIFT) program on the value of production share of wheat in the Prairies can be clearly discerned from the Figures. Seeded wheat acreage was lowered in 1970 in the Prairies to respond to a perceived glut in world grain supply. As a result wheat's relative value of production share declines considerably in 1970.

As with livestock, crop output at the Prairie level masks substantial variation amongst the provinces. All provinces have enjoyed tremendous growth in canola output since its introduction. Manitoba (Figure 4.9) has generally had a higher proportion of specialty crops, and barley's relative share has declined over time. Alberta (Figure 4.7) is characterized by a large stable relative share for barley and a growing tame hay share, a result of its large cattle sector. Saskatchewan (Figure 4.8) has been the dominant wheat producer; however, its share of wheat has also declined substantially, particularly from the 1980s onward. Although Saskatchewan's production of specialty crops began later than Manitoba or Alberta's, from the mid-nineties onward specialty crops account for a significant share of Saskatchewan's total value of crop production.

Figure 4.6 Prairie Crop Output: Value of Production Shares, 1940-2004

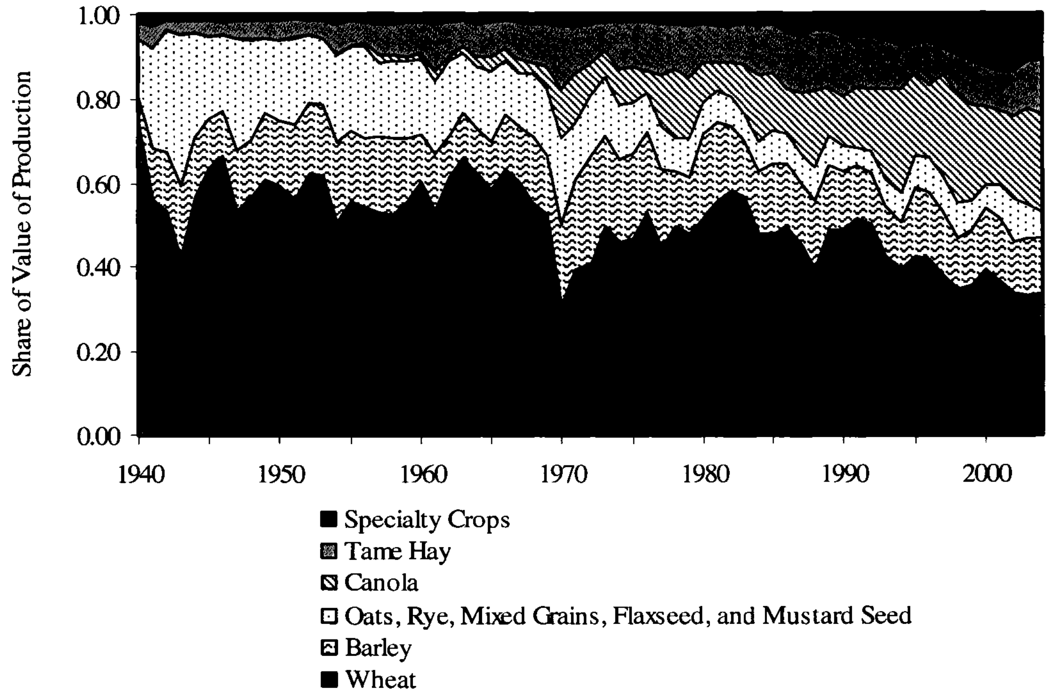


Figure 4.7 Alberta Crop Output: Value of Production Shares, 1940-2004

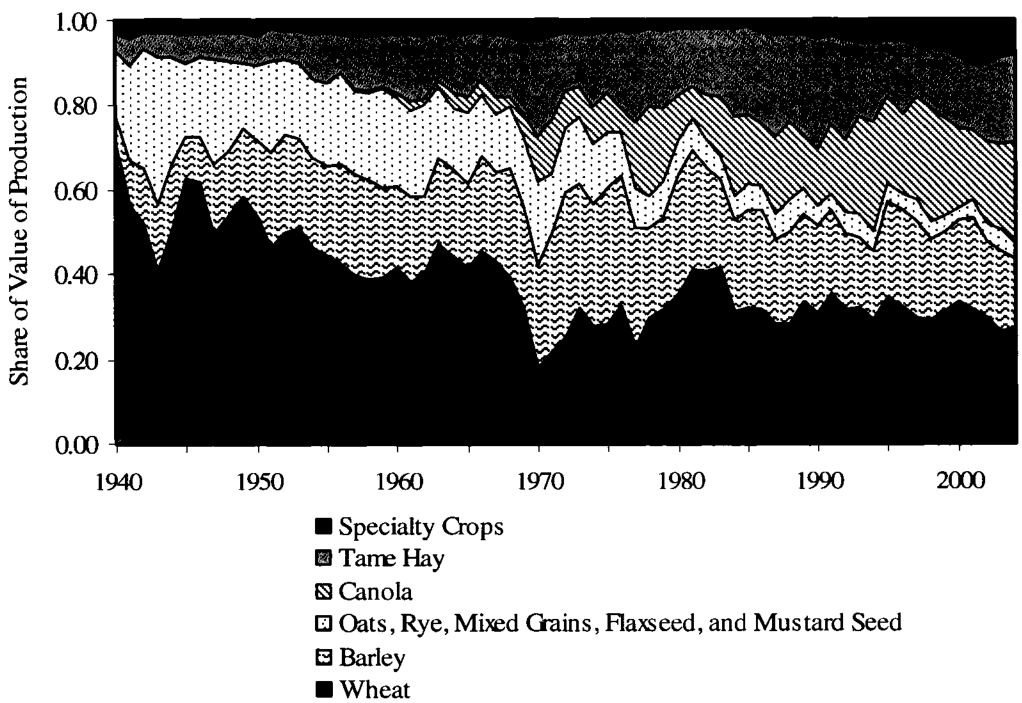


Figure 4.8 Saskatchewan Crop Output: Value of Production Shares, 1940-2004

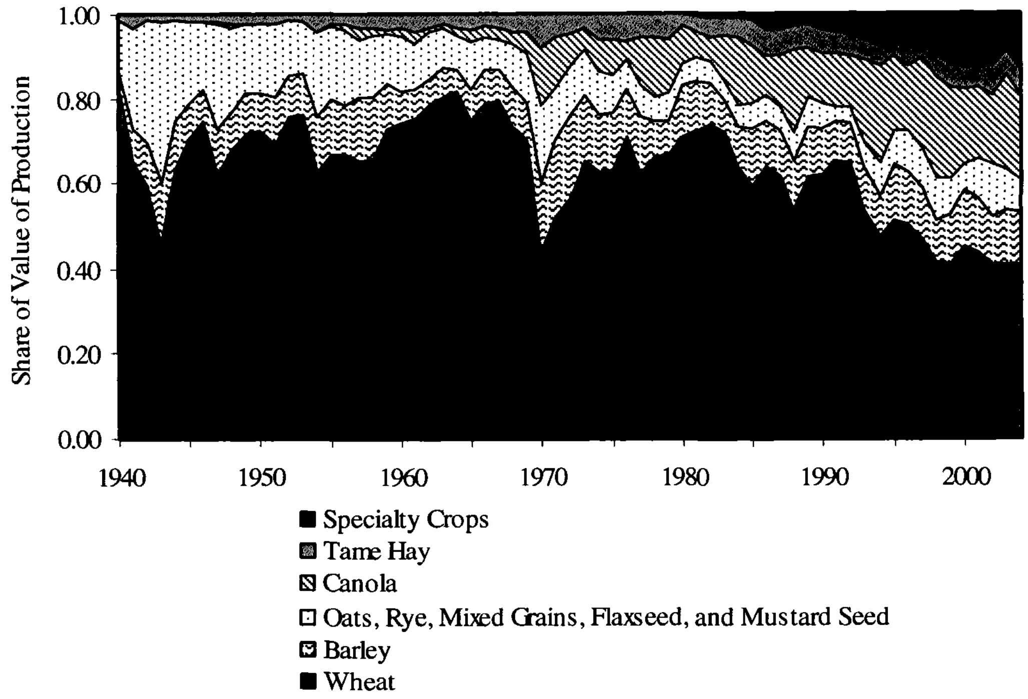
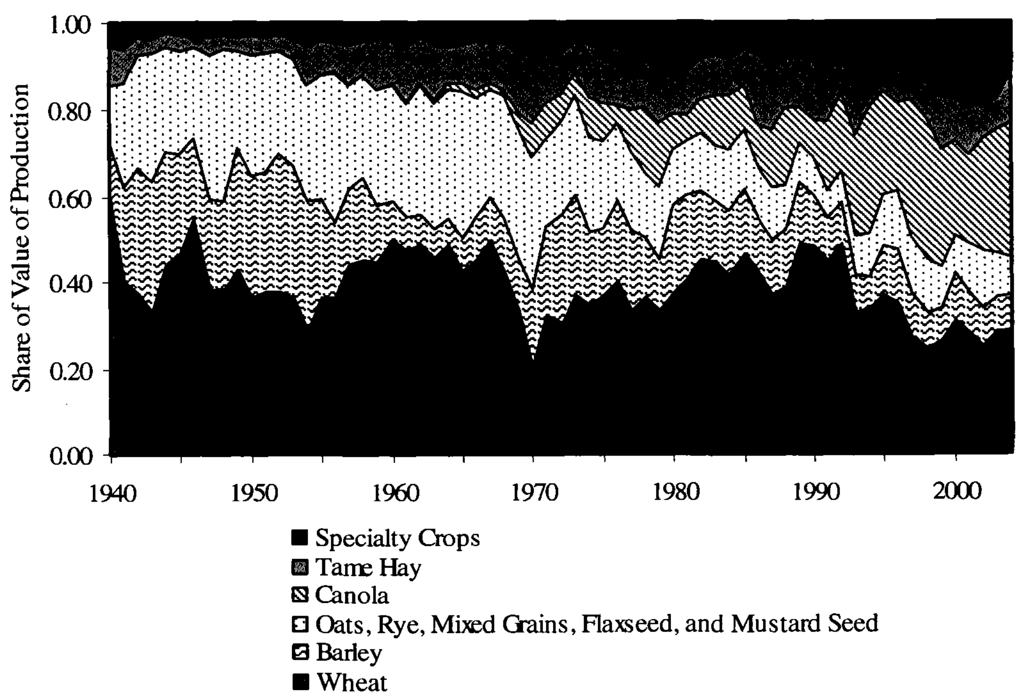


Figure 4.9 Manitoba Crop Output: Value of Production Shares, 1940-2004



4.3 Livestock and Crop Inputs

Allocating inputs between livestock and crop activities is not as straightforward as the attribution of outputs. Inputs are often not allocated to the separate crop and livestock activities, and many inputs are reported in stock form, while the relevant measure is their respective service flows. Section 4.3 illustrates the methodologies used in allocating the inputs between both activities, and to either activity. In addition, this Section presents a variety of descriptive statistics which permit an enhanced appreciation of the input structure of Prairie agriculture over the sixty-five years of the study.

4.3.1 Input Categories

To permit successful econometric analysis (i.e. productivity decomposition and measures of the production structure) the numerous inputs used in the study need to be aggregated into a smaller number of categories. This is done both for econometric reasons (e.g. degrees of freedom, and estimation issues) and to ensure an empirically tractable problem with results that can be interpreted effectively.

The input categories used in this study are capital, labour, land and materials. These are relatively conventional input categories (e.g. Adamowicz, 1986); however, there are a variety of other input categorization methodologies that can be employed. For example, Capalbo (1988) groups land and capital together into a single input category. The categories used in this study follow the original groupings used by Shiferaw and Fantino in their initial development of the data. The four input types chosen permit enough disaggregation for effective analysis of the production structure, yet are not so diffuse that estimation becomes problematic. Moreover, the input categories present intuitively reasonable partitions between the different input types, which facilitates the meaningful comparison of crops and livestock activities, as well as drawing general conclusions related to input use.

The composition of the various input categories is summarized in detail in Table 4.2. The price and quantity indexes for the inputs are taken from various Statistics Canada publications and from the provincial departments of agriculture.[6]

Table 4.2 Input Summary for Crops and Livestock Activities

Input Category	Crop Inputs	Livestock Inputs
Capital	• Machinery and equipment (M&E) • M&E repairs • M&E depreciation	• M&E • M&E repairs • M&E depreciation • Livestock inventory
Land	• Cropped land • Summer fallow • Buildings • Building repairs • Building depreciation • Property Tax	• Pasture (improved and native • Buildings • Building repairs • Building depreciation • Property Tax
Labour	• Unpaid labour • Paid labour	• Unpaid labour • Paid labour
Materials	• Fuel • Electricity • Telephone • Custom work • Twine, wire and containers • Misc. other expenses • Business insurance • Irrigation • Fertilizer and lime • Pesticides • Commercial seed • Retained seed • Crop Insurance	• Fuel • Electricity • Telephone • Custom work • Twine, wire and containers • Misc. other expenses • Business insurance • Feed • Artificial insemination and vet fees

[6] In many cases, only price data and total expenditure were available; consequently, implicit quantity indexes are derived.

4.3.2 Attribution of Inputs to Crop and Livestock Activities

Much agricultural input data are typically not subdivided between the livestock and crops activities. Consequently, the construction of the data requires a methodology through which input data can be subdivided into livestock and crop activities. Some inputs are unambiguous in nature and can easily be allocated to the appropriate activity (e.g. seed or feed). However, with other inputs (i.e. labour, capital, buildings and some materials) attribution is not clear-cut.

There are three distinct methodologies that are employed to allocate undivided inputs between the livestock and crops activities. The first methodology relies on a revenue maximization principal, where producers allocate inputs between crops and livestock activities based on the revenue received from either activity, in order to equalize the marginal revenue product between the two. Although theoretically appealing, this methodology, when implemented, yielded poor empirical results. A distinct shortcoming of this approach is that it assumes that the allocation of inputs will and can vary substantially year to year (a very short time horizon for the allocation of inputs, particularly durable inputs such as land and machinery), since both livestock and crops are characterized by substantial year to year variability in output, price and hence revenue. In addition, this approach assumes that producers are revenue maximizers, a much stronger assumption than cost minimization.

The second methodology allocates undivided inputs based on the value of cropped land and livestock, and although it proved superior to the revenue maximization approach, it nonetheless also yielded questionable empirical results. Allocation on the basis of cropped land and livestock implies a longer time horizon with regard to input use, since the value of cropped land for crops and the value of livestock inventory for livestock are typically not as variable as revenue over short time periods. However, the nominal, and even real, price of these two stocks can change quite rapidly (e.g. rising real land prices during the seventies). Overall, it is likely to be just as misleading to assume that inputs are allocated on the basis of the value of cropped land and livestock inventory as on the basis of revenue maximization.

A third methodology, which relies on agricultural census data, is used in this study; it performs well empirically and also appears to be an intuitively reasonable approach. Agricultural census data are used to allocate inputs between the crops and livestock activities, since the census reports the share of specific inputs (e.g. machinery and equipment) used in each sector. However, within the livestock sector, crops are grown, and within the crops sector, livestock is raised. Thus, a further methodology needs to be employed to calculate a sectoral share for livestock which includes *all* livestock (i.e. all livestock activities), and a sectoral share for crops which includes *all* crops (i.e. all crops activities). The rationale behind this approach is that it offers a simple, logical, and coherent approach to allocating inputs based on livestock and crop activities without regard to whether they occur in the livestock or crop sector.[7] Examining in detail the methodologies used for allocating capital, labour and buildings is instructive, since it illustrates the approaches explicitly. The allocation of other undivided inputs relies on these methodologies.

4.3.2.1 Allocation of Capital Using Census Shares Methodology

Capital allocation using the census shares methodology is based on a number of measures derived from Statistics Canada's Census of Agriculture: the respective dollar shares of machinery and equipment in the crops sector (*MC*) and in the livestock sector (*ML*); the respective shares of cropped land acreage in the crops sector (*CC*) and in the livestock sector (*CL*); the respective shares of livestock capital in the crops sector (*LC*) and in the livestock sector (*LL*).[8] The share of machinery and equipment devoted to crops activities in the livestock sector (*MLc*) can then be calculated as:

---

[7] The crop sector is comprised of farms that reported the majority of their farm income resulting from crops, and the livestock sector is comprised of farms reporting the majority of their farm income derived from livestock.

[8] The Census of Agriculture is released every five years and intervening values are interpolated using constant growth rates (i.e. the geometric mean), since the values from census to census typically do not vary significantly. Formally,

$$X_{i+1} = X_i [X_5 / X_1]^{\frac{1}{5}} \quad \text{where i = 1,2,3,4.}$$

Appropriate data are not available for the 1951 or 1956 censuses, so the missing data points are interpolated between the 1946 and 1961 censuses. The last Census of Agriculture was released in 2001; values for the 2001, 2002, 2003 and 2004 years are assumed to be identical to those reported for 2000. It is not anticipated that the projection for 2001-2004 will vary substantively from actual values.

(4.1) $MLc = MC\left[\frac{CL}{CC}\right]$

Similarly, the share of machinery and equipment devoted to livestock activities in the crops sector (*MCl*) can be calculated as:

(4.2) $MCl = ML\left[\frac{LC}{LL}\right]$

It follows that the overall share of machinery and equipment used for crop activities (*SMC*) can then be calculated, using equations (4.1) and (4.2), as:

(4.3) $SMC = MC + MLc - MCl = MC\left(1+\frac{CL}{CC}\right) - ML\left(\frac{LC}{LL}\right)$

and, the overall share of machinery and equipment used for livestock activities (*SML*) can be calculated as:

(4.4) $SML = ML + MCl - MLc = ML\left(1+\frac{LC}{LL}\right) - MC\left(\frac{CL}{CC}\right)$

4.3.2.2 Allocation of Labour Hours Using Census Shares Methodology

The allocation of labour hours to crops and livestock activities is similar in principal to the calculation of capital allocation. A number of measures can be derived from the Census of Agriculture: the respective shares of operator labour in the crops sector (*UWC*) and in the livestock sector (*UWL*); the respective shares of paid labour in the crops sector (*PWC*) and in the livestock sector (*PWL*); the respective shares of cropped land in the crops sector (*CC*) and in the livestock sector (*CL*); the respective shares of livestock in the crops sector (*LC*) and in the livestock sector (*LL*). The share of unpaid labour devoted to crops activities in the livestock sector (*UWLc*), and the share of unpaid labour devoted to livestock activities in the crops sector (*UWCl*) can then be calculated as:

(4.5) $UWLc = UWC\left[\frac{CL}{CC}\right]$ and (4.6) $UWCl = UWL\left[\frac{LC}{LL}\right]$

It follows that the overall share of unpaid labour used for crop activities ($SUWC$) can then be calculated, using equations (4.5) and (4.6), as:

$$(4.7) \quad SUWC = UWC + UWLc - UWCl = UWC\left(1 + \frac{CL}{CC}\right) - UWL\left(\frac{LC}{LL}\right)$$

The overall share of unpaid labour used for livestock activities is calculated in the same fashion, as are the calculations for paid labour, except the census shares for paid labour (PWC and PWL) are used in the place of the sectoral census shares of unpaid labour (UWC and UWL).

4.3.2.3 Allocation of Buildings Using Census Shares Methodology

The Census of Agriculture reports the share of land that the crop and livestock sectors use respectively. The Census also reports the share of land and buildings in each sector. The underlying rationale for allocating buildings between the two activities follows the ensuing line of reasoning: if the livestock sector's share of land and buildings is larger than their share of land then it must be explained by the fact that buildings are relatively more important to livestock farming than to crops farming (e.g. for animal shelter). Let SLC be the livestock sector's share of total cropped land, and let SCC be the crops sector's share of total cropped land. Further, let $SLLB$ be the livestock sector's share of land and buildings, and let $SCLB$ be the crop sector's share of land and buildings. If $RC = SCLB / SCC$ and $RL = SLLB / SLC$ then livestock's share of total buildings (SLB) can be written as: $SLB = RL / (RL+RC)$

$$(4.8) \quad SLB = \frac{RL}{(RL + RC))}$$

Similarly, crop's share of total buildings can be calculated as:

$$(4.9) \quad SCB = \frac{RC}{(RL + RC))}$$

4.3.2.3 Allocation of Other Inputs

Aside from capital, labour and buildings, a number of other inputs need to be attributed to crops and livestock activities. The allocation of these additional inputs relies either on one of the three methodologies already outlined, or on the crop and livestock's share of value of total output. The allocation methodologies chosen for each input reflect what are deemed to be reasonable proxies for actual input allocation between crop and livestock activities and are presented in Table 4.3.

Table 4.3 Additional Input Attribution Methodologies

Input Category	Input	Attribution Methodology
Land	Building repairs	Building share
Land	Building depreciation	Building share
Land	Property tax	Building share and land allocation
Materials	Fuel	Capital share
Materials	Business insurance	Value of livestock and crop output
Materials	Electricity	Building share
Materials	Telephone	Labour share
Materials	Miscellaneous other expenses	Value of livestock and crop output
Materials	Custom work	Value of livestock and crop output

4.3.3 Service Flow Imputation

The second key issue in the calculation of inputs is determining the appropriate service flows from inputs reported in stock form (i.e. land, buildings, machinery and equipment, and livestock inventory). For stock inputs there are as many as three components to their respective service flows: depreciation, repairs, and an opportunity cost (United States Department of Agriculture (USDA), 1980). In this study, depreciation and repairs are components of the service flows for only the buildings and machinery and equipment inputs.[9] Land and livestock inventory inputs are not considered to be subject to depreciation or repairs.[10] The determination of an appropriate measure of opportunity cost is somewhat more involved.

The concept of an opportunity cost component to the service flow from a stock or durable input follows from the assumption of rational behaviour on the part of the producer. A rational producer must receive some sort of productive service flow from a durable input (e.g. land) that they have invested in; otherwise they would choose to invest in a different type of asset yielding a superior service flow. The classic example in this regard is that a producer always has the option of buying a bond that pays a fixed rate of interest rather than investing in capital. Therefore, the rational producer's decision to invest in capital indicates that the service flow from capital is at least as great as the bond's interest payment. Assuming that equilibrium conditions hold (and ignoring risk and variability of return) the service flows of all investments should tend to converge. The preceding rationale informs the choice of methodology to arrive at a suitable measure of opportunity cost.

The most attractive approach in the calculation of opportunity cost is to use the product of a real interest rate and the nominal value of the stock. The real interest rate is calculated as a ten year moving average of the difference between the return on a basket of Government of Canada bonds and the inflation rate, and the nominal value of stocks for machinery and equipment, land and building, and livestock inventory are reported by Statistics Canada. This approach is theoretically appealing since it does not constrain the rate of return on a durable asset to be constant, since the real interest rate will vary over time. However, empirically, the measures of real interest tended to vary greatly over time. For example, the real rate of interest doubled from 1974 to 1975 and was negative from 1940 to 1948. It is untenable to assume that the opportunity cost of a stock would

---

[9] Depreciation estimates and repair expenses are reported by Statistics Canada for buildings and machinery and equipment, as are their related price indexes.

[10] The degradation of land can be interpreted as depreciation (e.g. erosion of top soil). However, the absence of accurate aggregate measures of land degradation throughout the Prairies in conjunction with uncertainty regarding the level of degradation or its agricultural impacts lead to the exclusion in this study of depreciation from the calculation of the service flow from the land input. It is also the case that in some Prairie regions the land base has been improved over time (e.g. with fertilizers).

double from one year to the next (with little change in the nominal value of the stock), or that it would be negative over an eight year period. Consequently, a second methodology is used to calculate opportunity costs.

A second option is to use a constant real rate of return to proxy opportunity cost. Past studies have used different rates of return for durable inputs and are presented in Table 4.4.

Table 4.4 Opportunity Cost Rates of Return for Durable Inputs

Author	Land Opportunity Cost (% Rate of Return)	Capital Opportunity Cost (% Rate of Return)
Islam (1982)	5.00	5.00
Adamowicz (1986)	2.75	Opportunity cost not considered
Rahuma (1989)	5.00	5.00
Veeman *et al* (1997)	4.00	Opportunity cost not considered

Veeman and Adamowicz's work does not assign an opportunity cost to capital under the assumption that the relevant service flow is the depreciation and repairs associated with capital. Nonetheless, the current study follows the USDA's recommendation (detailed in their 1980 report, *Measurement of U.S. Agricultural Productivity*) to include a measure of opportunity cost in addition to depreciation and repairs. The rate selected to proxy the opportunity cost of both land and capital is four percent. This is identical to the rate used by Veeman *et al* for the land input and strikes a balance between the lower bound rate of Adamowicz at 2.75 percent and the higher bound rates of Rahuma and Islam at 5.00 percent. Sensitivity analysis shows that the productivity growth estimates are not significantly affected by using either Adamowicz's or Rahuma and Islam's rates of return.

4.3.4 Input Descriptive Statistics

The foregoing methodologies permit the attribution of inputs to crop and livestock activities. It is informative then to review how input use has changed over time. Diagrammatically, the most efficient way to assess changing input use is to review the input cost shares presented in Figures 4.10, 4.11 and 4.12. Input cost shares are included only for the Prairie level, given that the cost shares of the individual provinces are very similar in structure.

Figure 4.10 clearly shows four trends in input use. First, labour as an input cost share has declined appreciably over time, a finding echoed in both crops and livestock (Figures 4.11 and 4.12). Second, the use of materials has increased dramatically, particularly in the case of crops; this is a result of the increased use of fertilizers, and pesticides over time, but also due to the increased cost of fuel and electricity. From Figure 4.12 it can also be seen that materials make up a larger share of livestock inputs, relative to crop inputs, because of the substantial cost of livestock feed. The third general observation relates to capital. Figure 4.10 shows that the Prairie's capital share gradually increases from 1940 to the late 1970s, and levels off afterward. These findings are persistent for crops. With livestock, on the other hand, a lower level of capital use is recorded and there is a less distinctive trend in capital use. The final observation, present in all three Figures, is a gradually increasing cost share for land. This is likely caused by two factors: rapidly rising land and building prices (in excess of the rate of inflation), and a gradual increase in the area of land being farmed and structures required for the growing livestock industry.

Figure 4.10 Prairie Agriculture Input Cost Shares, 1940-2004

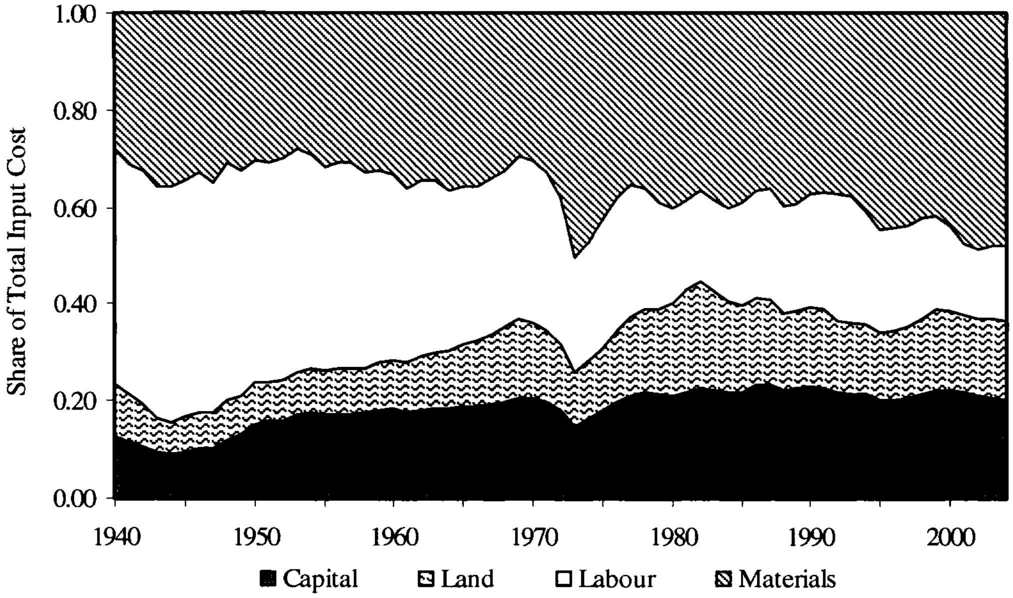


Figure 4.11 Prairie Crops Input Cost Shares, 1940-2004

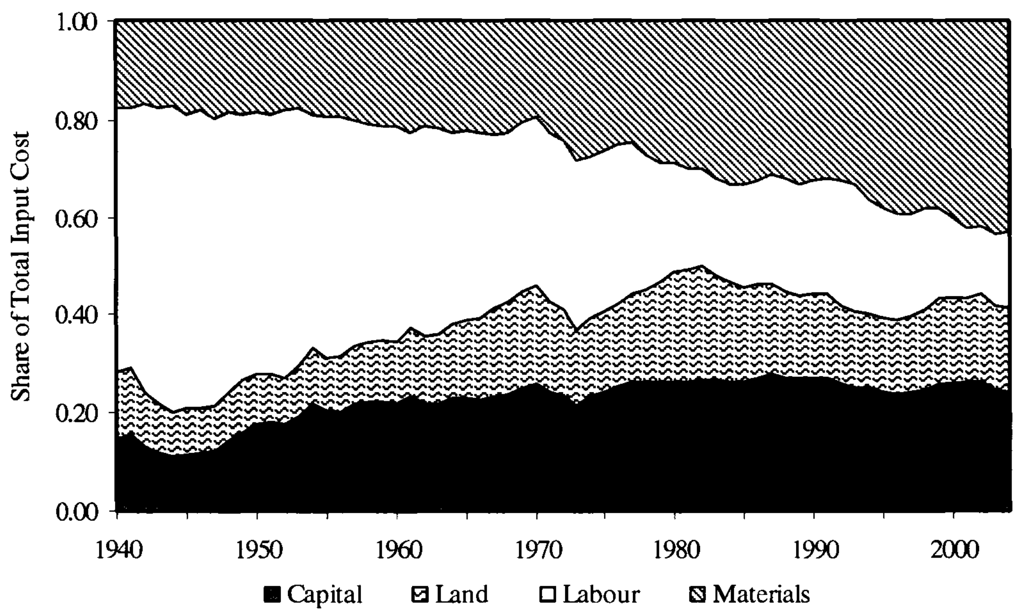
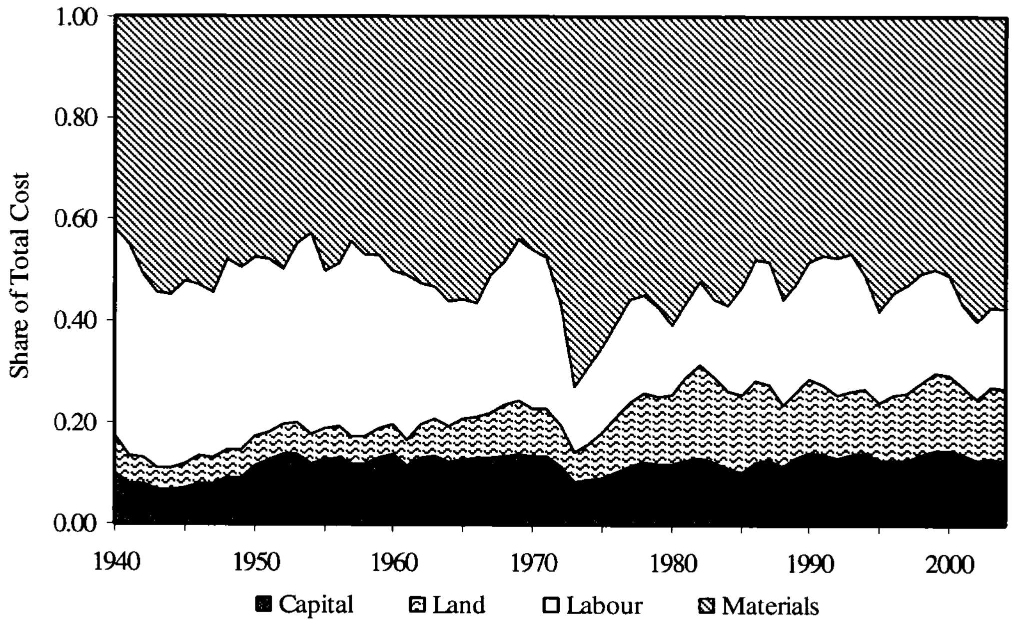


Figure 4.12 Prairie Livestock Input Cost Shares, 1940-2004



CHAPTER 5: EMPIRICAL RESULTS I – GROWTH RATES

5.1 Index Number Results and Methodology

By implementing the index number procedures detailed in Chapter 2, the input and output data reviewed in the preceding Chapter can be used to derive estimates of TFP growth in Prairie agriculture. Two other measures of interest can also be derived using similar indexing procedures.

5.1.1 Terms of Trade and Returns to Cost

Terms of trade (ToT^T) are a ratio of output prices to input prices, and relate the output prices received by producers to the input prices paid by producers. Formally, using Törnqvist-Theil indexing procedures, terms of trade growth is comparable to TFP growth as written in equations (2.6), (2.7) and (2.8) derived from Capalbo (1988), with input and output prices replacing input and output quantities:

$$(5.1) \quad \dot{ToT}^T = \dot{P}^T - \dot{W}^T$$

$$(5.2) \quad \dot{P}^T = \sum_{j=1}^{m} \left(\frac{r_{j,t} + r_{j,t-1}}{2} \right) \left[\ln p_{j,t} - \ln p_{j,t-1} \right]$$

$$(5.3) \quad \dot{W}^T = \sum_{i=1}^{n} \left(\frac{s_{i,t} + s_{i,t-1}}{2} \right) \left[\ln w_{i,t} - \ln w_{i,t-1} \right]$$

$\dot{P}^T$ is the growth rate of output prices, $\dot{W}^T$ is the growth rate of input prices, $r_{j,t}$ is the revenue share of the output *j* in period *t*, $s_{i,t}$ is the cost share of input *i* in period *t*, $p_{j,t}$ is the price of output *j* in period *t*, and $w_{i,t}$ is the price of input *i* in period *t*.

Terms of trade growth provides a measure of the cost-price environment faced by an economic entity. Declining (negative) terms of trade growth indicates input prices that are increasing relative to output prices over time, and points to the cost pressures facing an industry.

By using both terms of trade and TFP, *returns to cost* can also be calculated as follows:

$$(5.4) \quad RtC^T = \frac{Q^T}{X^T} \cdot \frac{P^T}{W^T} = TFP^T \cdot ToT^T$$

where TFP^T is the ratio of output quantities (Q^T) to input quantities (X^T) and ToT^T is the ratio of output prices (P^T) to input prices (W^T). In growth rate terms expression (5.4) can be written as:

$$(5.5) \quad \dot{RtC}^T = \dot{TFP}^T + \dot{ToT}^T$$

The returns to cost provide a crude measure of relative profitability. For instance, an economic entity facing declining terms of trade can be profitable if its productivity growth exceeds the rate of decline in its terms of trade. More specifically, if a firm faces terms of trade that decline at a rate of two percent a year while the firm's productivity grows at a rate of three percent per annum then the firm's returns to cost will grow at a rate of one percent a year (i.e. 3% + (-2%) = 1%). Although a limited measure, returns to cost is effective in providing a broad appraisal of the profitability and competitive pressures faced by an economic entity or sector.

5.1.2 Average Annual Compound Growth Rates

There are a number of ways to report annual growth rates – for example, either compound or simple average annual growth rates. The representative growth rate methodology adopted in this study follows Veeman's (1975) methodology. Average annual compound growth rates are calculated by fitting exponential growth curves. The subsequent expression is estimated using least squares estimation:

$$\ln g_t = \alpha + \beta \cdot T + \varepsilon_t$$

where $t = 1,2,\ldots,T$

g_t = the index in period t, where the index measures either TFP, inputs, outputs, terms of trade, or returns to cost

$\beta = \ln(1+r)$

$T =$ the time period

$\varepsilon_t =$ the random disturbance term

The trend rate of growth (r) can be calculated from the estimated β as follows:

$$r = \exp[\beta] - 1$$

Using this methodology, trend growth rates for TFP, inputs, outputs, terms of trade, and returns to cost are obtained and reported in Tables 5.1 through 5.4.

A caveat regarding trend growth rates is that they tend to be sensitive to the endpoints chosen. If the start point is uncharacteristically small (large) in magnitude the overall growth rate will be biased upward (downward); the same result holds if the end point is especially large (small) in value. The preceding admonition is particularly relevant when studying agriculture, since weather (i.e. droughts or flooding) can significantly affect the growth rates if care is not exercised in the choice of endpoints. In Tables 5.1 through 5.4 the only endpoint occurring during a period of significant drought is 1980. Caution should also be exercised when assessing growth rates derived over short time periods, since the limited number of data points can yield a biased (unrepresentative) growth rate. In this study, the shortest time periods considered are eleven years in length (1994-2004).

5.1.3 TFP, Input, Output, Terms of Trade, and Returns to Cost

Figures 5.1 through 5.8 illustrate graphically the indexes from which the growth rates reported in Tables 5.1 to 5.4 are calculated. Graphical representations offer a visual method to assess the overarching growth trends in the various indexes. The graphical approach is a valuable counterpart to the numerical results presented in the subsequent Tables.[1]

[1] Graphic representations are only presented for livestock and crop agriculture. They are not presented for aggregate agriculture. Aggregate measures are reported in the attached Tables, and no significant information is offered in a graphical presentation of aggregate agriculture that cannot be gleaned from the individual crops and livestock Figures. Graphic representations of crop and livestock terms of trade and returns to cost indexes can be found in Appendix C (Figures C.1 to C.8).

Average annual compound growth rates of TFP, input, output, terms of trade, and return to cost are reported for the Prairies and the individual provinces. The growth rates for the Prairies and its component provinces are assessed for crops and livestock activities individually and for both activities together. It is important to note that calculations at the aggregate level (both crops and livestock activities combined) and at the Prairie level (Alberta, Saskatchewan, and Manitoba combined) are *not* a simple weighted average of either the growth rates reported for the individual crops and livestock activities or agriculture in the three individual Prairie provinces. Instead, the inputs and outputs from the two activities, or the three provinces, are aggregated and new indexes are calculated using Törnqvist-Theil indexing procedures to arrive at new estimates for aggregate agriculture, or the Prairies. Consequently, some counterintuitive results may occur; for instance, during the 1980-2004 period (Table 5.1), Prairie TFP growth is higher for aggregate agriculture than for either crops or livestock (this is also an indication of endpoint issues due to the 1980 drought).

5.2 Prairie Results: TFP, Input, Output, Terms of Trade, and Returns to Cost

A number of general conclusions can be drawn from the results reported in Table 5.1. First, over the entire 1940 to 2004 period, Prairie agriculture in aggregate records an annual average compound productivity growth rate of 1.56 percent. The aggregate finding, however, masks the substantial divergence between the annual productivity growth rate in crops (1.77 percent) and livestock (0.65 percent) over the 1940-2004 period.[2] During the sub-periods, crops TFP growth has been relatively consistent at 1.55, 1.89 and 1.77 percent per annum; however, the final sub-period breakdown shows crop TFP growth slowing markedly over the final ten years. From 1994 to 2004 productivity growth is only 0.59 percent a year, and is accompanied by negative input and output growth. Livestock, in contrast, exhibits substantial TFP growth of 2.49 percent per annum from 1994 to 2004, and an expansion in output of 3.51 percent per year. By

---

[2] These findings are similar to results reported by Huffman and Evenson (1993) for agriculture in the U.S. Northern Plains (North and South Dakota, Nebraska, and Kansas) over the 1950 to 1982 period; specifically, annual TFP growth of 2.05, 0.81, and 1.68 respectively for crops, livestock, and aggregate agriculture.

examining the sub-periods, (1940-1959, 1960-1979, 1980-2004) it can be observed that livestock TFP growth increases over time from negative 0.02 to 0.33 and then to 1.12 percent per annum, with a corresponding growth in output. In terms of cost pressures, the terms of trade decline for crops and livestock for the whole 1940-2004 period, and for each sub-period, with crops facing consistently worse (more negative) terms of trade than livestock. The returns to cost are very different between crops and livestock; crops returns to cost are positive for only one sub-period (1960-1979, the period of greatest crops output expansion and TFP growth), while the returns to cost are positive for livestock in every sub-period but one (1940-1959).[3]

The estimates reported in Table 5.1 provide a portrait of Prairie agriculture. Crops farming has traditionally been the more productive enterprise, yet has faced stronger cost pressures and has been less profitable than livestock farming. However, over time, productivity growth in livestock increases, and is highest during the 1994 to 2004 period, while TFP growth in crops stagnates during this same period.

Figures 5.1 and 5.2 support the conclusions drawn from Table 5.1. Figure 5.1 points to relatively slower crops TFP growth over the 1940 to 1960 period. In addition, the 2001/02 drought offers a partial explanation for the decline in crops productivity from 1994 to 2004, since output declines precipitously with only a slight reduction in inputs. Nevertheless, it is difficult to support the counterfactual – that in the absence of drought the rate of crops productivity growth would not have slowed. Crops productivity growth over the 1994 to 2004 period appears to be more generally stagnant.

With regard to livestock, Figure 5.2 shows a period of productivity advance for livestock from the early 1950s to the mid 1960s, and then very slow productivity growth (if any) until the early 1990s. Starting in the late 1980s output growth begins to expand rapidly, and is followed some five years later by very rapid TFP growth.

---

[3] The returns to cost measures tend to overstate the negative position of agriculture since they do not account for support payments producers receive.

Table 5.1 Prairie Crops/Livestock: Annual Growth Rates of TFP, Input, Output, Terms of Trade, and Returns to Cost (Percent)

Period	Activity	$\dot{Q}$ (Outputs) %	$\dot{X}$ (Inputs) %	$\dot{TFP}$ %	$\dot{ToT}$ (Terms of Trade) %	$\dot{RtC}$ (Returns to Cost) %
1940-2004	Crops	2.68	0.90	1.77	-2.57	-0.85
	Livestock	1.56	0.90	0.65	-0.29	0.36
	Aggregate	2.43	0.86	1.56	-1.93	-0.40
1940-1959	Crops	1.80	0.25	1.55	-2.94	-1.44
	Livestock	-0.27	-0.24	-0.02	-0.43	-0.46
	Aggregate	1.22	-0.03	1.25	-2.19	-0.97
1960-1979	Crops	3.60	1.68	1.89	-1.29	0.57
	Livestock	1.49	1.16	0.33	-0.33	0.00
	Aggregate	2.95	1.45	1.48	-1.05	0.41
1980-2004	Crops	1.82	0.05	1.77	-2.39	-0.67
	Livestock	2.85	1.70	1.12	-0.50	0.62
	Aggregate	2.38	0.57	1.80	-1.96	-0.19
1994-2004	Crops	-0.53	-1.12	0.59	-3.38	-2.81
	Livestock	3.51	0.99	2.49	-1.61	0.84
	Aggregate	1.36	-0.42	1.79	-3.18	-1.45

Figure 5.1 Prairie Crops: TFP, Input and Output Indexes, 1940-2004

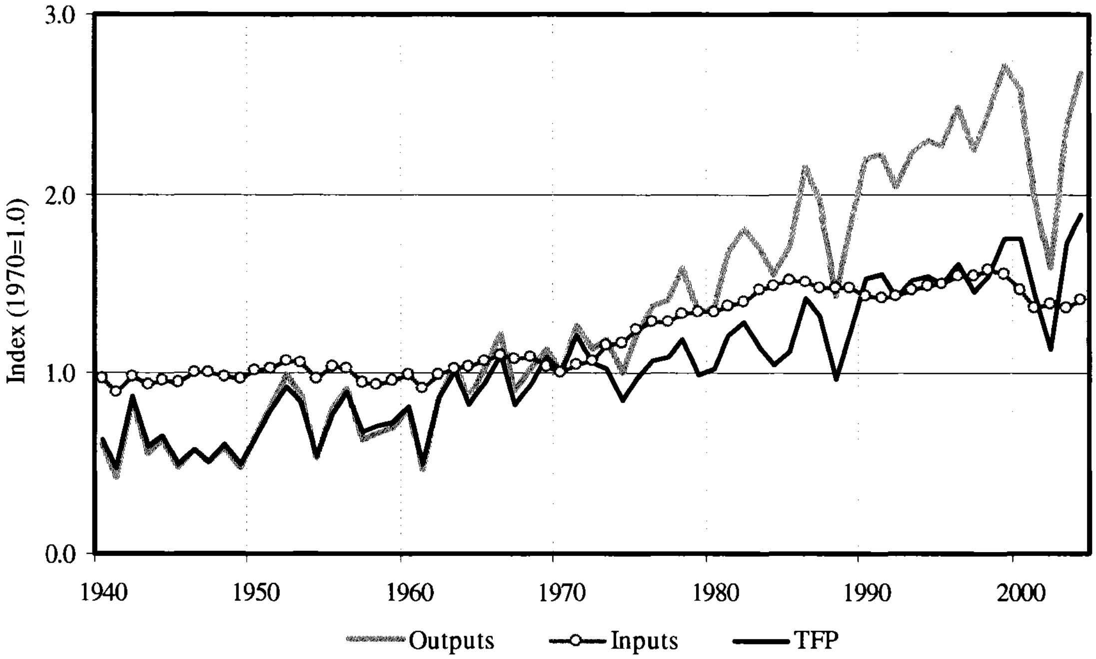
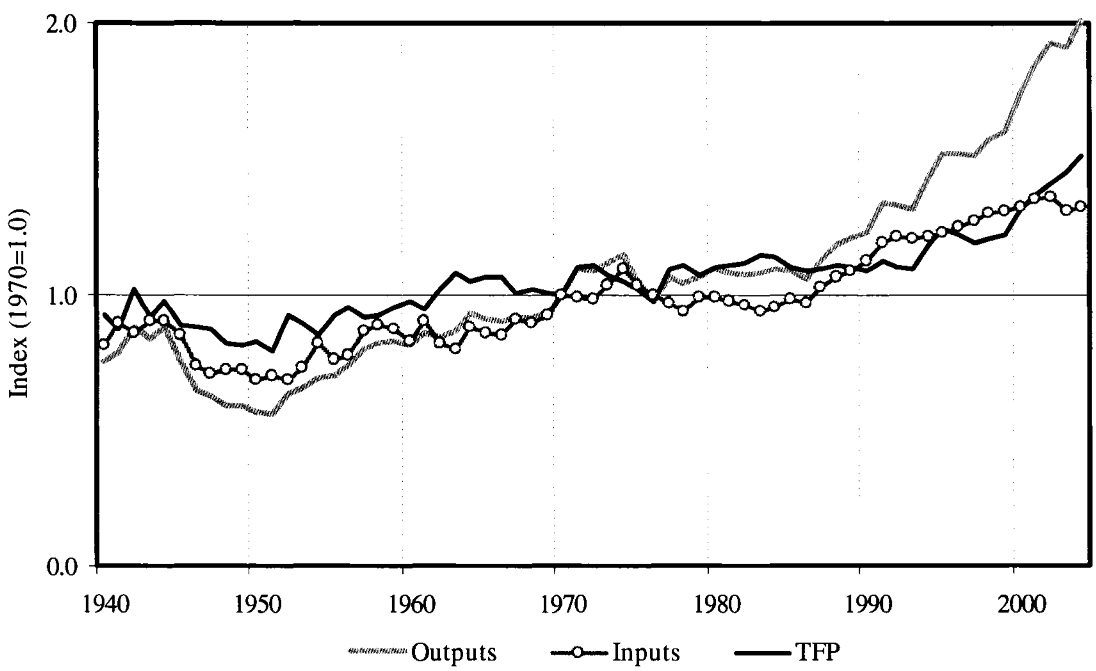


Figure 5.2 Prairie Livestock: TFP, Input and Output Indexes, 1940-2004



This Section has provided a broad overview of livestock and crops farming in the Prairies. The following three Sections assess the developments that have occurred in the individual provinces. Many of the trends found in Prairie agriculture are persistent throughout the separate provinces; nonetheless, important differences characterize the individual provinces.

5.2.1 Alberta Results

The productivity growth trends in Alberta agriculture closely mirror those reported for the Prairies, although productivity growth is typically lower in Alberta for both crops and livestock agriculture. Overall, crops farming is more productive than livestock for the entire 1940 to 2004 period. As with the Prairies, crops productivity growth slows considerably over the 1994 to 2004 period, and in fact becomes negative (-0.33 percent per annum). Livestock TFP growth increases over the same period to 0.58 percent a year; however, this is a much slower rate of growth than that reported over the same period for the Prairies (2.49 percent per annum). The terms of trade and returns to cost growth measures reflect cost pressures and profitability that are consistently worse for crops farming than livestock.

Graphically, Figures 5.3 and 5.4 for Alberta crops and livestock are quite similar to Figures 5.1 and 5.2 for the Prairies. The TFP index for Alberta crops does not record as strong growth as in the Prairies. The 2001/02 drought had a relatively large impact on Alberta crop output and may account for a portion of the slower crops TFP growth, relative to Prairie crops growth, over the 1994 to 2004 period. More specifically, the 2001/02 drought had a considerable impact on Alberta and Saskatchewan crops and a limited impact on Manitoba crops. The 2001 drought had similar consequences for both Alberta and Saskatchewan crops farming, while the 2002 drought resulted in poorer harvests in Alberta relative to Saskatchewan. Nonetheless, relatively poor weather conditions are not a credible explanation for the entirety of Alberta's lagging crops productivity, since, during many periods of superior growing conditions, Alberta's crops productivity has continued to lag behind Saskatchewan's and the Prairies' crops productivity growth. Sluggish productivity growth in Alberta is even more distinct in livestock. Aside from 1950 to the mid 1960s very little productivity growth has occurred.

The dramatic increase in output from the late eighties onward is accompanied by substantial input growth, and hence low productivity growth, from the early nineties onward, relative to that recorded for Prairie livestock.

Table 5.2 Alberta Crops/Livestock: Annual Growth Rates of TFP, Input, Output, Terms of Trade, and Returns to Cost (Percent)

Period	Activity	$\dot{Q}$ (Outputs) %	$\dot{X}$ (Inputs) %	$\dot{TFP}$ %	$\dot{ToT}$ (Terms of Trade) %	$\dot{RtC}$ (Returns to Cost) %
1940-2004	Crops	2.81	1.13	1.65	-2.65	-1.04
	Livestock	1.84	1.29	0.54	-0.24	0.31
	Aggregate	2.51	1.16	1.34	-1.75	-0.43
1940-1959	Crops	2.09	0.72	1.36	-2.75	-1.43
	Livestock	0.51	0.27	0.24	-0.34	-0.10
	Aggregate	1.66	0.41	1.25	-1.98	-0.76
1960-1979	Crops	3.71	2.05	1.62	-1.46	0.14
	Livestock	1.65	1.46	0.19	-0.30	-0.11
	Aggregate	2.94	1.74	1.18	-1.09	0.08
1980-2004	Crops	1.11	0.07	1.04	-2.31	-1.29
	Livestock	2.40	2.06	0.34	-0.39	-0.06
	Aggregate	1.84	0.85	0.99	-1.62	-0.65
1994-2004	Crops	-1.26	-0.94	-0.33	-2.91	-3.23
	Livestock	1.33	0.75	0.58	-1.45	-0.88
	Aggregate	0.57	-0.24	0.81	-2.75	-1.96

Figure 5.3 Alberta Crops: TFP, Input and Output Indexes, 1940-2004

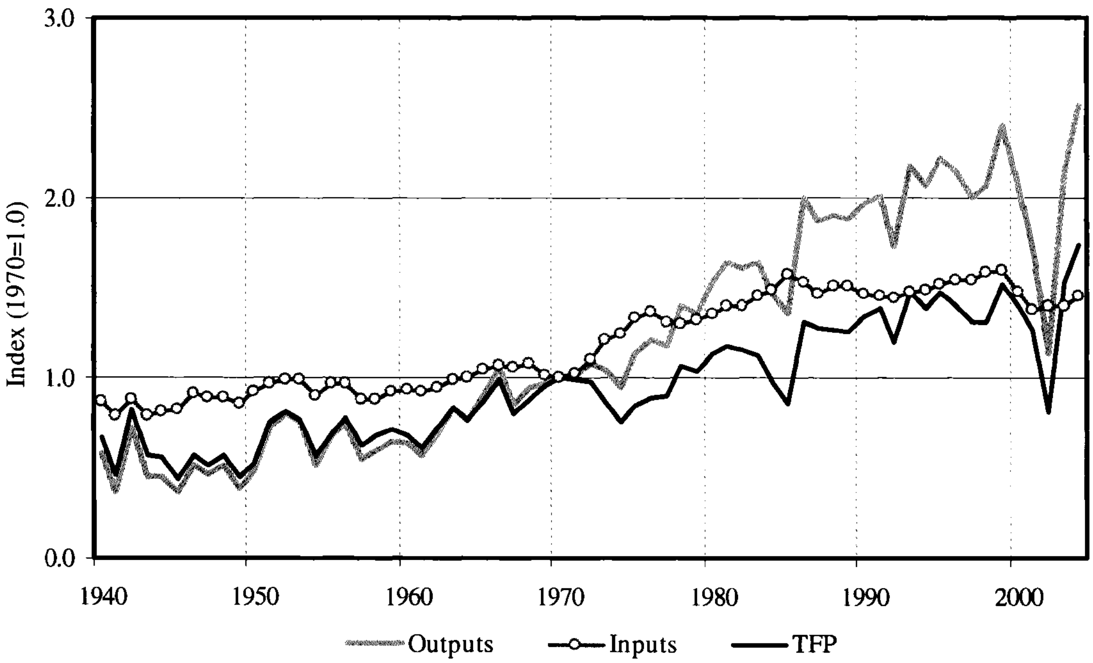
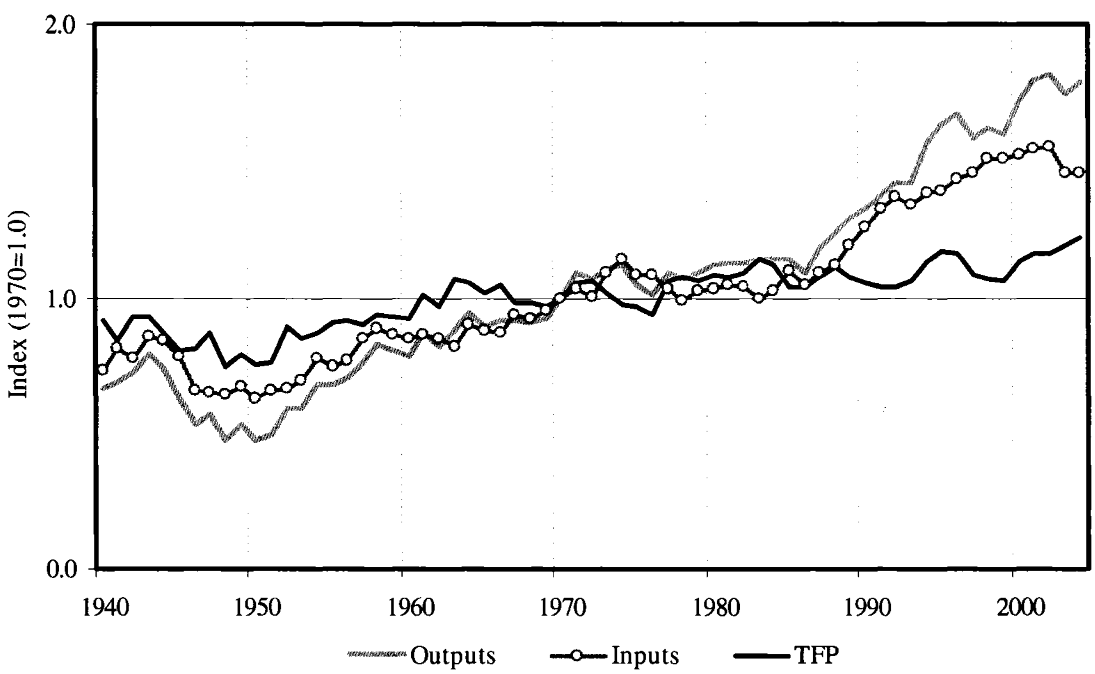


Figure 5.4 Alberta Livestock: TFP, Input and Output Indexes, 1940-2004



5.2.2 Saskatchewan Results

The results for Saskatchewan (Table 5.3) are again similar to those found in the Prairies. However, Saskatchewan crops and livestock have recorded somewhat higher productivity growth than Alberta from 1940 to 2004 and during all but one of the reported sub-periods (the 1940-1959 sub-period for livestock). The terms of trade and returns to cost are also comparable to Alberta's, with the exception of the 1980 to 2004 period where Saskatchewan livestock appears to have been a considerably more profitable industry in comparison to its Alberta counterpart.

Graphically, the striking declines in crops output during the droughts of 1988 and 2001/02 are visible in Figure 5.5. The large droughts in conjunction with an increase in productivity growth to 2.11 percent per annum, over the 1980 to 2004 period, suggest that weather may not exert a dominant influence on productivity growth. In Alberta, where, at least in terms of output decline, the drought of 1988 was not as severe, TFP growth declined to 1.04 percent a year over the same 1980-2004 period. Figure 5.6, also indicates some differences in the livestock TFP growth. In Saskatchewan livestock the dramatic expansion in output begins in the early nineties rather than the late eighties as is the case with Alberta and the Prairies. In addition, rapid livestock TFP growth occurs at the same time as output growth. There is no lag between increased output growth and TFP growth like that taking place in Alberta and the Prairies - a lag off some five to ten years. Productivity growth in Saskatchewan livestock over the final ten years is also much more pronounced than that occurring in Alberta and the Prairies: TFP growth of 4.28 percent per annum compared with 0.58 and 2.49 percent a year respectively in Alberta and the Prairies over the 1994-2004 period.

Table 5.3 Saskatchewan Crops/Livestock: Annual Growth Rates of TFP, Input, Output, Terms of Trade, and Returns to Cost (Percent)

Period	Activity	$\dot{Q}$ (Outputs) %	$\dot{X}$ (Inputs) %	$\dot{TFP}$ %	$\dot{ToT}$ (Terms of Trade) %	$\dot{RtC}$ (Returns to Cost) %
1940-2004	Crops	2.49	0.72	1.76	-2.46	-0.75
	Livestock	0.87	0.27	0.59	-0.46	0.13
	Aggregate	2.22	0.56	1.65	-2.10	-0.48
1940-1959	Crops	2.01	0.04	1.97	-3.10	-1.19
	Livestock	-1.20	-0.81	-0.39	-0.52	-0.91
	Aggregate	1.14	-0.30	1.45	-2.40	-0.99
1960-1979	Crops	3.43	1.40	2.00	-1.07	0.92
	Livestock	1.08	0.89	0.19	-0.37	-0.18
	Aggregate	2.92	1.22	1.68	-0.97	0.69
1980-2004	Crops	2.07	-0.04	2.11	-2.29	-0.23
	Livestock	2.79	0.91	1.86	-0.56	1.29
	Aggregate	2.43	0.17	2.26	-2.10	0.11
1994-2004	Crops	-1.02	-1.40	0.39	-3.71	-3.33
	Livestock	5.09	0.77	4.28	-1.68	2.54
	Aggregate	0.72	-0.91	1.64	-3.65	-2.06

Figure 5.5 Saskatchewan Crops: TFP, Input and Output Indexes, 1940-2004

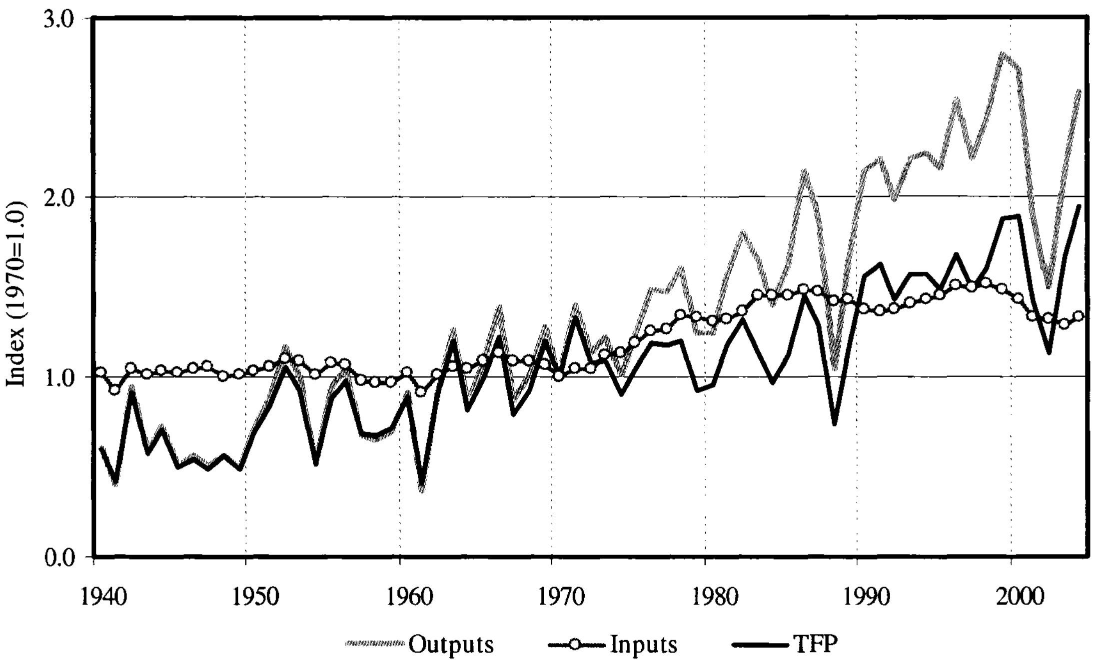
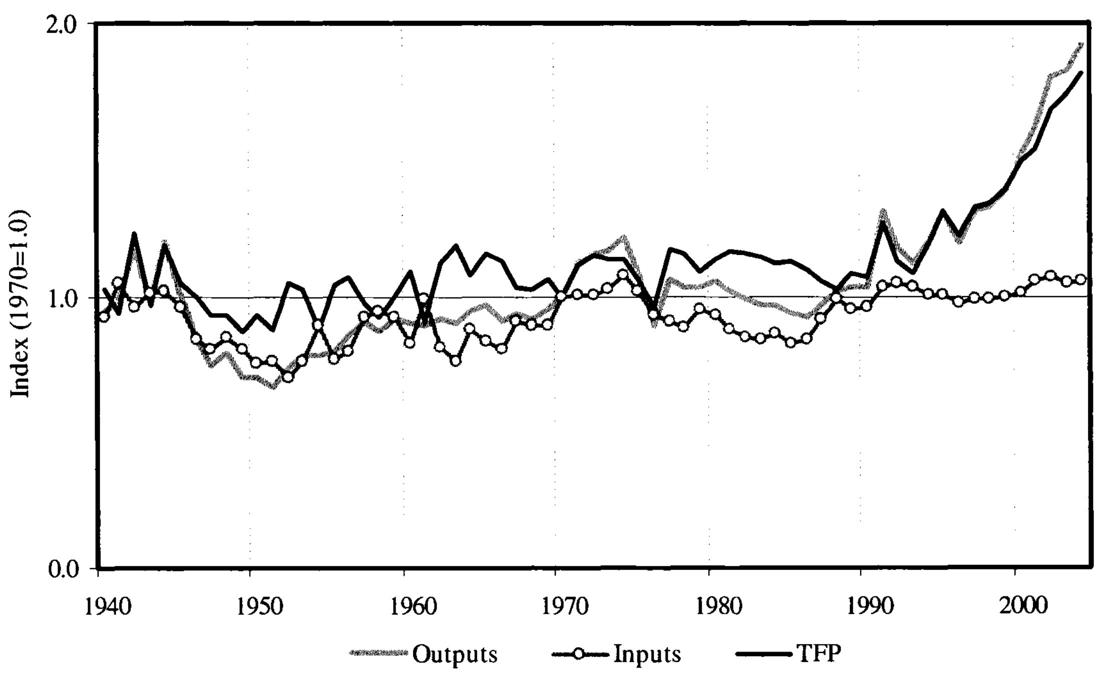


Figure 5.6 Saskatchewan Livestock: TFP, Input and Output Indexes, 1940-2004



5.2.3 Manitoba Results

As has been indicated in the preceding Sections, Alberta and Saskatchewan crops and livestock agriculture are comparable in a number of respects. From Table 5.4 it can be seen that Manitoba crops and livestock display some distinctive trends. Overall, productivity growth in Manitoba crops and livestock is significantly higher than that found in either Alberta or Saskatchewan. Manitoba crops display relatively low annual productivity growth of 0.90 percent over the first sub-period, while Alberta and Saskatchewan report relatively strong productivity growth of 1.36 and 1.97 percent per annum. The following sub-periods in Manitoba crops display robust TFP growth of 2.67 and 2.47 percent per annum for the 1960-1979 and 1980-2004 periods. Unlike Alberta and Saskatchewan, Manitoba crops TFP increases over the final 1994-2004 sub-period to 2.70 percent a year. In livestock, as well, Manitoba displays rapid productivity advance. TFP growth increases in each sub-period, from 0.04 to 0.78 to 2.13 percent per annum in the 1940-1959, 1960-1979 and 1980-2004 sub-periods respectively. Livestock TFP growth in the final sub-period (1994-2004) is considerable at 5.33 percent per annum, with output growth of 7.45 percent a year.

Graphically, Figure 5.7 shows the steady and relatively rapid crops productivity growth, especially from 1960 onward. The drought of 1988 has a pronounced impact on output, while the 2001/02 drought is not as significant. Figure 5.8 indicates the steady productivity growth for Manitoba livestock from 1950 until the mid-nineties when it accelerates rapidly. The relatively large livestock output expansion that begins in the early nineties is also apparent.

Table 5.4 Manitoba Crops/Livestock: Annual Growth Rates of TFP, Input, Output, Terms of Trade, and Returns to Cost Results (Percent)

Period	Activity	$\dot{Q}$ (Outputs) %	$\dot{X}$ (Inputs) %	$\dot{TFP}$ %	$\dot{ToT}$ (Terms of Trade) %	$\dot{RtC}$ (Returns to Cost) %
1940-2004	Crops	3.07	0.93	2.12	-2.78	-0.72
	Livestock	1.85	0.87	0.97	-0.20	0.76
	Aggregate	2.80	0.87	1.92	-1.99	-0.11
1940-1959	Crops	0.90	0.00	0.90	-2.95	-2.08
	Livestock	-0.42	-0.45	0.04	-0.57	-0.53
	Aggregate	0.54	-0.29	0.83	-2.17	-1.36
1960-1979	Crops	4.36	1.64	2.67	-1.62	1.01
	Livestock	1.64	0.86	0.78	-0.43	0.35
	Aggregate	3.37	1.30	2.05	-1.21	0.81
1980-2004	Crops	2.72	0.24	2.47	-2.85	-0.45
	Livestock	4.01	1.85	2.13	-0.72	1.39
	Aggregate	3.50	0.76	2.72	-2.38	0.27
1994-2004	Crops	1.84	-0.83	2.70	-3.45	-0.85
	Livestock	7.45	2.01	5.33	-1.79	3.45
	Aggregate	4.27	0.13	4.14	-3.12	0.89

Figure 5.7 Manitoba Crops: TFP, Input and Output Indexes, 1940-2004

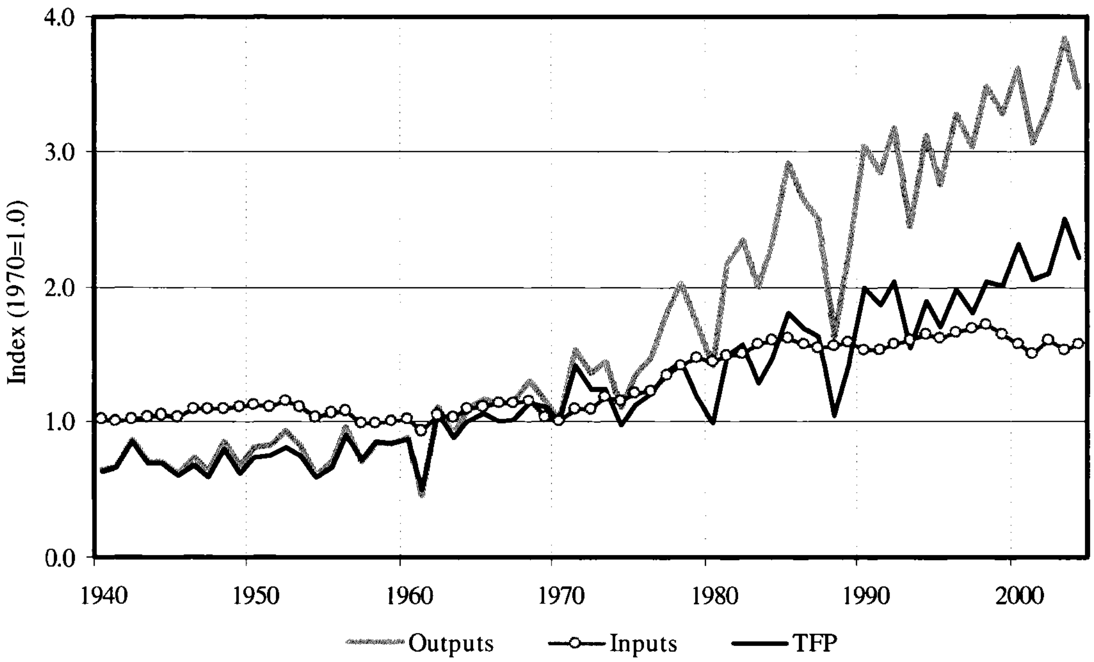
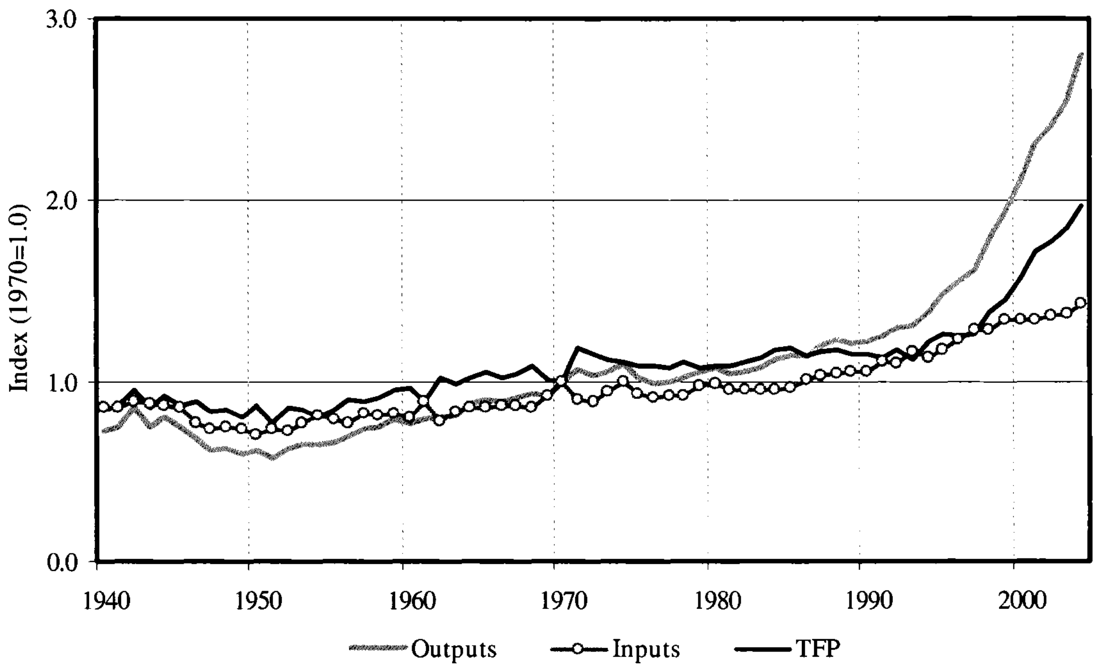


Figure 5.8 Manitoba Livestock: TFP, Input and Output Indexes, 1940-2004



5.2.4 Provincial Comparison and Summary

At this point a comparison of productivity growth in the Prairie provinces is of value; first of all, in order to review the conclusions reached in this Chapter (prior to delving into a more detailed empirical analysis of the productivity estimates in Chapter 6), and secondly to summarize four key questions that the preceding analysis raises regarding productivity growth in Prairie agriculture.

In Table 5.5, the productivity results presented in Tables 5.2, 5.3 and 5.4 are restated. The most striking parallel amongst the provinces is the lower productivity growth recorded in livestock farming relative to crops. Livestock TFP growth does, however, trend upward over time in both Manitoba and Saskatchewan, and to a lesser extent Alberta. In contrast, Alberta and Saskatchewan both report declining TFP growth in crops during the 1994-2004 period. A final general observation is that although the individual livestock and crops activities display divergent productivity growth in each province, the relative rankings between provinces are consistent; Manitoba exhibits the best productivity growth in both livestock and crops activities, followed by Saskatchewan in both activities and then Alberta. Provincial rankings that are persistent, both in terms of livestock and crops farming, are unlikely to be purely coincidental.

Table 5.5 Alberta, Saskatchewan and Manitoba Crop and Livestock TFP Annual Growth Rates

		1940-2004 %	1940-1959 %	1960-1979 %	1980-2004 %	1994-2004 %
Crops	Alberta	1.65	1.36	1.62	1.04	-0.33
	Saskatchewan	1.76	1.97	2.00	2.11	0.39
	Manitoba	2.12	0.90	2.67	2.47	2.70
Livestock	Alberta	0.54	0.24	0.19	0.34	0.58
	Saskatchewan	0.59	-0.39	0.19	1.86	4.28
	Manitoba	0.97	0.04	0.78	2.13	5.33

Four basic questions arise from preceding results:

1. *What accounts for the lower productivity growth rates in livestock farming relative to crops?*

2. *Why has livestock productivity growth accelerated considerably over the past twenty-five years in Saskatchewan and Manitoba, while only moderately in Alberta?*

3. *Why has crops productivity growth slowed in Alberta and Saskatchewan from 1994 to 2004, and increased in Manitoba over the same period?*

4. *Why are both crops and livestock productivity growth rates somewhat higher in Saskatchewan than in Alberta, and considerably higher in Manitoba?*

These four questions will be explored in subsequent Chapters, since a valid explanation regarding the productivity growth that has occurred should, at a minimum, be able to answer these questions. In Chapter 6 an empirical examination of how the different productivity growth rates occur is undertaken, with a focus on the respective roles of technical change and scale effects. In Chapter 7 causal explanations for the productivity growth are evaluated, in order to establish the key determinants of productivity growth in Prairie agriculture.

CHAPTER 6: EMPIRICAL RESULTS II – PRODUCTIVITY DECOMPOSITION AND MEASURES OF PRODUCTION STRUCTURE

6.1 Econometric Modeling

In Chapter 3 the decomposition of productivity growth was described conceptually and illustrated formally. A number of ancillary measures were also discussed that are associated with productivity growth and can be derived from the econometric estimates (i.e. economies of scope and the bias of technical change). In this Chapter the models used to calculate these measures are formally developed and estimated. The salient econometric results are reported and their implications for productivity growth are then discussed.

6.1.2 Single-Output and Multi-Output Translog Cost Functions Formally

To formally model Prairie agriculture in Chapter 3 it was indicated that the use of a translog cost function is an effective approach. Since the divergence in productivity growth rates between crops and livestock agriculture and amongst the individual provinces is of interest, twelve cost functions are estimated in total – three apiece for the Prairies, Alberta, Saskatchewan and Manitoba. Two single-output cost functions, representing livestock and crops agriculture, are estimated for each of the individual provinces and the Prairies, and a multi-output cost function is estimated for aggregate agriculture in each of the three provinces and the Prairies.

Following Coelli (1998) the single-output translog cost function can be written as follows:

$$\begin{aligned}\ln C &= \alpha_0 + \alpha_1(\ln Q) + \frac{1}{2}\delta_{11}(\ln Q)^2 + \sum_{r=1}^{4}\beta_r(\ln W_r) + \frac{1}{2}\sum_{r=1}^{4}\sum_{s=1}^{4}\gamma_{rs}(\ln W_r)(\ln W_s) \\ &+ \sum_{r=1}^{4}\rho_r(\ln W_r)(\ln Q) + \phi_t(T) + \frac{1}{2}\phi_{tt}(T)^2 + \sum_{r=1}^{4}\gamma_{rt}(\ln W_r)(T) + \delta_t(\ln Q)(T)\end{aligned} \quad (6.1)$$

T is a time trend variable intended to capture disembodied technological progress; W_1 is the price index of capital; W_2 is the price index of land; W_3 is the price index of labour (the agricultural wage rate); W_4 is the price index of materials; and Q is a quantity index representing either crops or livestock output. To improve the efficiency of the estimation input cost shares, derived using Shephard's lemma, are conventionally estimated along with equation (6.1) and can be written as:

$$S_r = \frac{W_r \cdot X_r}{\sum_{s=1}^{4} W_s \cdot X_s} = \frac{\partial C}{\partial W_r} \cdot \frac{W_r}{C} = \frac{\partial \ln C}{\partial \ln W} = \qquad r = 1,\ldots,4 \tag{6.2}$$

$$\beta_r + \sum_{s=1}^{4} \gamma_{rs} (\ln W_s) + \rho_r (\ln Q) + \gamma_{rt} (T)$$

Revenue shares are not traditionally included in the estimation of single-output cost functions. The revenue share requires additional data, either revenue or output price data. The use of the revenue share imposes the further restriction of competitive behaviour on producers, since through its derivation output price is set equal to marginal cost. The assumption of competitive behaviour (marginal cost pricing) is necessary to ensure theoretical consistency with the behavioural assumptions implicit in the index number calculation of TFP.[1] Through its use of cost and revenue shares the Törnqvist-Theil indexing procedure imposes the assumption of competitive behaviour (Capalbo, 1988). The revenue share is written as:

$$R = \frac{P \cdot Q}{C} = MC \cdot \frac{Q}{C} = \frac{\partial C}{\partial Q} \cdot \frac{Q}{C} = \frac{\partial \ln C}{\partial \ln Q} = \tag{6.3}$$

$$\alpha_1 + \sum_{r=1}^{4} \rho_r (\ln W_r) + \delta_{11} (\ln Q) + \delta_t (T)$$

In the multi-output case equations (6.1), (6.2) and (6.3) are written as (6.4), (6.5) and (6.6); where Q_1 is the output quantity index for livestock and Q_2 is the output quantity index for crops:

[1] See Ray (1982) for a spirited defense of the assumption of marginal cost pricing in the estimation of a multi-output cost function. Ray suggests that the assumption of competitive behaviour is not generally overly restrictive.

$$\ln C = \alpha_0 + \sum_{i=1}^{2}\alpha_i(\ln Q_i) + \frac{1}{2}\sum_{i=1}^{2}\sum_{j=1}^{2}\delta_{ij}(\ln Q_i)(\ln Q_j) + \sum_{r=1}^{4}\beta_r(\ln W_r) +$$

$$(6.4)\quad \frac{1}{2}\sum_{r=1}^{4}\sum_{s=1}^{4}\gamma_{rs}(\ln W_r)(\ln W_s) + \sum_{i=1}^{2}\sum_{r=1}^{4}\rho_{ir}(\ln W_r)(\ln Q_i) +$$

$$\phi_t(T) + \frac{1}{2}\phi_{tt}(T)^2 + \sum_{r=1}^{4}\gamma_{rt}(\ln W_r)(T) + \sum_{i=1}^{2}\delta_{it}(\ln Q_i)(T)$$

$$(6.5)\quad S_r = \beta_r + \sum_{s=1}^{4}\gamma_{rs}(\ln W_s) + \sum_{i=1}^{2}\rho_{ir}(\ln Q_i) + \gamma_{rt}(T) \qquad r = 1,\ldots,4$$

$$(6.6)\quad R_i = \alpha_i + \sum_{j=1}^{2}\delta_{ij}(\ln Q_j) + \sum_{r=1}^{4}\rho_{ir}(\ln W_r) + \delta_{it}(T) \qquad i = 1,2$$

To ensure consistency with theory, and improve the robustness of the estimates, symmetry (i.e. $\gamma_{rs} = \gamma_{sr}$, $r \neq s$, and $\delta_{ij} = \delta_{ji}$, $i \neq j$) is assumed, and linear homogeneity in input prices is imposed *a priori* by the following restrictions:[2]

$$(6.7)\quad \sum_{r=1}^{4}\beta_r = 1, \text{ and } \sum_{r=1}^{4}\gamma_r = \sum_{s=1}^{4}\gamma_s = \sum_{r=1}^{4}\sum_{s=1}^{4}\gamma_{rs} = \sum_{i=1}^{2}\sum_{r=1}^{4}\rho_{ir} = \sum_{r=1}^{4}\gamma_{rt} = 0$$

In addition, the cost shares are restricted so that they sum to one at each sample point. No such restriction is placed on revenue share(s), since at any data point total revenue may be greater, less, or equal to total cost.

The econometric estimation of the cost function, input cost shares and revenue share(s) is carried out by jointly estimating the system of equations (6.1), (6.2) and (6.3) in the single-output case ((6.4), (6.5) and (6.6) in the multi-output case) using Zellner's seemingly unrelated regression (SUR) method. The system approach is used due to the high degree of multicollinearity present in the independent variables, resulting in imprecise estimates if the cost function is estimated alone. To improve the efficiency of the system estimation, equality between coefficients is imposed across the equations, and as noted above, homogeneity in input prices and symmetry are imposed *a priori*. Since the four cost shares, by definition, sum to one, the materials cost share is dropped to

---

[2] The symmetry and homogeneity restrictions presented are for the multi-output case. Derivation of the restrictions for the single-input case is straightforward.

prevent over-identification. By calculating maximum likelihood estimates, using an iterative procedure, the estimates are invariant to the share equation dropped.[3]

The coefficient estimates, other dimensions of the production structure, and detail relating to the econometric testing of the model can be found in Appendix D. Only the results of direct relevance to the study of productivity growth are included in subsequent Sections of this Chapter.

6.2 Decomposition of Productivity: Results

In Chapter 3, using either equation (3.7) in the single-output case or (3.9) in the multi-output case, the shift in the cost function ($\dot{B}$) and the cost-output elasticity (ε_{CQ}) need to be derived to decompose the estimates of productivity growth reported in Chapter 5. From the multi-output translog cost function presented in equation (6.4) the shift in the cost function and cost-output elasticity can be calculated as follows:

$$(6.8) \quad \dot{B} = \frac{1}{C}\frac{\partial g}{\partial t} = \frac{\partial \ln C}{\partial t} = \phi_t + \phi_{tt} + \sum_{r=1}^{4} \gamma_{rt}(\ln W_r) + \sum_{i=1}^{2} \delta_{it}(\ln Q_i)$$

$$(6.9) \quad \varepsilon_{CQ_i} = \frac{\partial \ln C}{\partial \ln Q_i} = \alpha_i + \delta_{ii}(\ln Q_i) + \sum_{i \neq j} \delta_{ij}(\ln Q_j) + \sum_{r=1}^{4} \rho_{ir}(\ln W_r) + \delta_{it}(T)$$

Equations (6.8) and (6.9) can be calculated at either the point of approximation or using sample means. Calculation at the point of approximation is computationally simple, and intuitively attractive, since the calculation is carried out at the point about which the translog cost function is "expanded".[4] However, $\dot{TFP}$ and $\dot{Q}$ are average annual compound growth rates for the 1940-2004 period, rather than point estimates. Consequently, it is more reasonable to decompose TFP growth at the sample mean, rather than at the point of approximation. Empirically, the results at the sample mean are more robust, with smaller reported residuals.

---

[3] The SUR estimation procedure as described follows Greene (2003).

[4] Capalbo's (1988) TFP decomposition takes place at the point of approximation. The independent variables are normalized around the point of approximation (the midpoint of the sample 1972) and the time trend is zero at this point - thus equations (6.8) and (6.9) simplify to $\phi_t + \phi_{tt}$ and α_i respectively.

6.2.1 Competitive Behaviour Assumption

The results of equations (6.8) and (6.9) are reported in Tables 6.1 and 6.2. Table 6.1 assumes that competitive behaviour is imposed by using the revenue share(s) in the system estimation. Table 6.2 does not employ revenue shares in the estimation, simply assuming cost minimization. The results reported in Tables 6.1 and 6.2 vary dramatically, indicating that the assumption of competitive behavior is a pivotal assumption. Under the competitive behaviour assumption, Table 6.1 shows that technical change, as represented by an inward shift in the cost function, is a relatively large component of TFP growth. Without the imposition of the competitive behaviour assumption (Table 6.2) the results are basically reversed; scale effects (i.e. increasing returns to scale) play the dominant role, and the impact of technical change is predominantly negative. The theoretical rationale for imposing the competitive behaviour assumption is clear. In addition, the results reported in Tables 6.1 and 6.2 provide, on three fronts, empirical justification for assuming competitive behaviour.

First of all, the negative (regressive) technical change reported in Table 6.2 indicates stagnant or even deteriorating development and adoption of technology. This could happen only if the technology employed is unable to keep pace with the challenges faced by livestock and crops agriculture in the Prairies (for example, animal diseases or soil degradation). It is clear, though, that regressive technical change is not an accurate characterization of Prairie agriculture over the past sixty-five years. At a minimum, the role of genetics and process innovations in livestock and the plethora of new seed varieties and crops introduced over the past century make the hypothesis of low or negative technical change in Prairie agriculture implausible.

Secondly, the measured residuals suggest that the competitive behaviour assumption is required. In Table 6.2, the residual measures vary between negative 47.4 and 24.1 percent of TFP growth with an average deviation of 17.1 percent. When competitive behaviour is imposed the residual range shrinks, negative 19.8 to 11.7 percent, with an average deviation of 7.9 percent. The residuals denote measurement errors and other factors not included under technical change and scale effects (for example, changes in technical efficiency). Average residuals of 17.1 percent appear improbably large, specifically in comparison with the more reasonable estimates obtained under the competitive behaviour assumption.

Third, all estimates reported in Table 6.1 are statistically significant at the one percent level. In contrast, only seventeen of twenty-four estimates in Table 6.2 are statistically significant at the one percent level, two others are significant at the five percent level, and the remaining five estimates are not statistically significant at the five percent level. From the standpoint of statistical significance the results reported in Table 6.1 are evidently superior.

There are sound theoretical and empirical grounds to dismiss the results obtained without assuming competitive behaviour; accordingly, the following assessment of the results will focus exclusively on the estimates reported in Table 6.1.

Table 6.1 TFP Decomposition at Sample Mean with Imposition of Competitive Behaviour, 1940-2004

		TFP Growth Rate [a]	Scale Effects	Technical Change	Residual
Aggregate	Prairies	1.56 (100.0)	0.29** (18.7)	1.12** (71.6)	0.15 (9.7)
	Alberta	1.34 (100.0)	0.27** (20.2)	0.95** (70.8)	0.12 (9.0)
	Saskatchewan	1.65 (100.0)	0.18** (11.2)	1.37** (83.2)	0.09 (5.6)
	Manitoba	1.92 (100.0)	0.33** (17.3)	1.37** (71.3)	0.22 (11.4)
Crops	Prairies	1.77 (100.0)	0.30** (17.2)	1.43** (80.8)	0.04 (2.0)
	Alberta	1.65 (100.0)	0.08** (4.9)	1.57** (94.7)	0.01 (0.4)
	Saskatchewan	1.76 (100.0)	0.30** (16.9)	1.49** (84.5)	-0.03 (-1.5)
	Manitoba	2.12 (100.0)	0.35** (16.5)	1.70** (80.4)	0.07 (3.1)
Livestock	Prairies	0.65 (100.0)	0.33** (50.5)	0.26** (39.5)	0.07 (9.9)
	Alberta	0.54 (100.0)	0.28** (51.0)	0.20** (37.3)	0.06 (11.7)
	Saskatchewan	0.59 (100.0)	0.37** (62.4)	0.34** (57.4)	-0.12 (-19.8)
	Manitoba	0.97 (100.0)	0.35** (36.0)	0.52** (53.2)	0.11 (10.8)

** and * denote statistical significance at the one and five percent level respectively.
Figures in parentheses denote percentages.
[a] TFP growth rates used in this Table are in Tables 5.1, 5.2, 5.3 and 5.4.

Table 6.2 TFP Decomposition Results at Sample Mean without Competitive Behaviour Assumption, 1940-2004

		TFP Growth Rate [a]	Scale Effects	Technical Change	Residual
Aggregate	Prairies	1.56 (100.0)	2.78** (179.4)	-1.32** (-84.7)	0.08 (5.3)
	Alberta	1.34 (100.0)	1.89 (141.1)	-0.80** (-59.7)	0.25 (18.5)
	Saskatchewan	1.65 (100.0)	2.84** (172.3)	-0.87** (-52.9)	-0.32 (-19.5)
	Manitoba	1.92 (100.0)	2.54* (132.6)	-1.05** (-54.8)	0.43 (22.3)
Crops	Prairies	1.77 (100.0)	2.37** (133.8)	-0.38** (-21.4)	-0.22 (-12.5)
	Alberta	1.65 (100.0)	2.12** (128.3)	-0.30* (-18.0)	-0.17 (-10.3)
	Saskatchewan	1.76 (100.0)	2.58** (147.00)	-0.37** (-21.2)	-0.45 (-25.8)
	Manitoba	2.12 (100.0)	2.26** (106.6)	-0.19 (-8.9)	-0.05 (2.4)
Livestock	Prairies	0.65 (100.0)	0.76** (115.9)	-0.14 (-21.0)	0.03 (5.1)
	Alberta	0.54 (100.0)	0.40** (72.8)	0.08 (14.7)	0.07 (12.5)
	Saskatchewan	0.59 (100.0)	0.63** (106.9)	0.24** (40.5)	-0.28 (-47.4)
	Manitoba	0.97 (100.0)	0.88** (90.7)	-0.14 (-14.8)	0.23 (24.1)

** and * denote statistical significance at the one and five percent level respectively. Figures in parentheses denote percentages.

[a] TFP growth rates used in this Table are in Tables 5.1, 5.2, 5.3 and 5.4.

6.2.2 Crops Results[5]

Technical change is the largest component of estimated productivity growth in crops farming. For Alberta, Saskatchewan and Manitoba, respectively, 94.7, 84.5 and 80.4 percent of TFP growth over the 1940-2004 period is composed of technical change. The role of scale effects is economically significant for Manitoba and Saskatchewan at 16.9 and 16.5 percent respectively. For Alberta, however, the role of scale is negligible, with only 4.9 percent of its TFP growth attributable to scale effects. The implication of these results is that productivity growth in crops is driven largely by technological advance, especially in Alberta. Saskatchewan and Manitoba have also been able to reap substantive productivity gains from increasing aggregate crops output and associated scale economies over the last sixty-five years. An additional point of interest is the relatively low residuals reported for crops: 0.4, negative 1.5 and 3.1 percent for Alberta, Saskatchewan and Manitoba respectively. It can be inferred from the small residuals that measurement error is low and that the vast majority of productivity growth is captured by technical change and scale; there is a limited role left for other factors such as changes in technical efficiency.

6.2.3 Livestock Results

In regard to the livestock results, scale plays a much larger role in TFP growth. For Alberta and Saskatchewan the majority of TFP growth is composed of scale effects (51.0 and 62.4 percent respectively). Manitoba livestock productivity growth is mainly composed of technical change (53.2 percent), but scale effects are still relatively large at thirty-six percent. The results imply that the growth in aggregate livestock output and associated scale economies in the three Prairie provinces has been a significant driver of

---

[5] Two points regarding the results reported in Tables 6.1 and 6.2 should be made. First, it is worth reiterating that the analysis in this study takes place at the aggregate (provincial) level. Therefore, the decomposition results may not necessarily reflect the respective roles of scale and technical change in individual livestock and crops farms. Second, in the summary of results for crops, livestock and aggregate agriculture the individual provinces are reviewed. The Prairie estimates included in Tables 6.1 and 6.2 are not directly discussed, since they are an aggregation of the more interesting results reported for the individual provinces. The Prairie estimates are presented in the Tables to ensure completeness and provide overall measures.

productivity growth over the 1940-2004 period. The most obvious explanations for the role of scale in livestock productivity growth are the development of intensive livestock operations (feedlots, hog barns etc.) that have emerged over time and as aggregate provincial livestock output has expanded. In contrast to crops, the reported residuals for livestock are large. This may be an indication of measurement error and the presence of other factors implicated in livestock productivity growth; it may also be a reflection of the complexity and diversity of the production processes involved in livestock relative to crops.

6.2.4 Aggregate Results

The decomposition procedure for aggregate agriculture (joint production of crops and livestock) involves using a multi-output cost function. In Section 3.3.3 the point was made that the use of multi-output cost functions in the context of agricultural production is theoretically limiting. Nonetheless, the estimates provide additional insight into productivity growth in Prairie agriculture. The results point to the prominent role that technical change plays in TFP growth for aggregate agriculture in the Prairie provinces. Scale maintains an important role in TFP growth for Alberta and Manitoba at 20.2 and 17.3 percent respectively, and a lesser role for Saskatchewan at 11.2 percent.

For Alberta and Manitoba the roles of scale and technical change in the productivity growth of aggregate agriculture rest between the estimates for their constituent crops and livestock activities (e.g. in Alberta 20.2 percent of aggregate agricultural productivity growth is attributable to scale effects, which is higher than the 4.9 reported for Alberta crops and lower than the 51.0 percent reported for Alberta livestock). Interestingly though, for Saskatchewan the 11.2 percent of aggregate agriculture TFP growth attributable to scale effects is lower than its measures of scale effects for crops or livestock at 16.9 and 62.4 percent respectively. This is an indication of diseconomies of scope between Saskatchewan crops and livestock farming. If economies of scale for crops and livestock are larger when analyzed as separate activities rather than as a joint process, diseconomies of scope are evident. The evidence in Table 6.1 of economies or diseconomies of scope in Alberta and Manitoba agriculture is ambiguous. The ensuing analysis in Section 6.4.1 presents a methodology to explicitly test for the presence of (dis)economies of scope. The implications of (dis)economies of scope will be related in this Section.

6.2.5 Decomposition Summary

The decomposition of productivity growth is illuminating since it clarifies the respective roles of technical change and scale. It is evident that over the entire 1940-2004 period that productivity growth in crops has relied to a great extent on technical change with scale playing a secondary role in Saskatchewan and Manitoba. In livestock productivity growth, the scale of production has been the dominant force for Alberta and Saskatchewan, and although smaller in Manitoba it has still been relatively important. The foregoing is valuable information concerning productivity growth in Prairie agriculture, yet it is essential to recognize the limitations of this approach.

The TFP growth rate that is decomposed is an annual average compound growth rate for the entire 1940-2004 period. This is a representative growth rate for an extended period of time and can obscure the variations occurring over time. In Chapter 5, productivity growth is shown to fluctuate over time and it is plausible that the impacts of technical change and scale have also varied over time. Section 6.3 expands on the econometric modeling of Section 6.1 to explore the changes in the respective components of productivity growth over time, in order to arrive at a more complete understanding of the dynamic process of productivity growth in Prairie agriculture over the past sixty-five years.

6.3 The Dynamics of Technical Change and Scale

The estimated translog cost functions can be used to provide measures of technical change and scale at each of the sixty-five sample points (or years) in the study. By graphing the sixty-five points a representation of the changes in technical change and scale over time can be obtained.[6] The dynamical processes of returns to scale and

---

[6] The accuracy of the translog functional form diminishes at sample points distant from the point of approximation, which in this study is the mid-point of the sample, 1972. Conclusions relating to points distant from the sample mid-point should be treated with care.

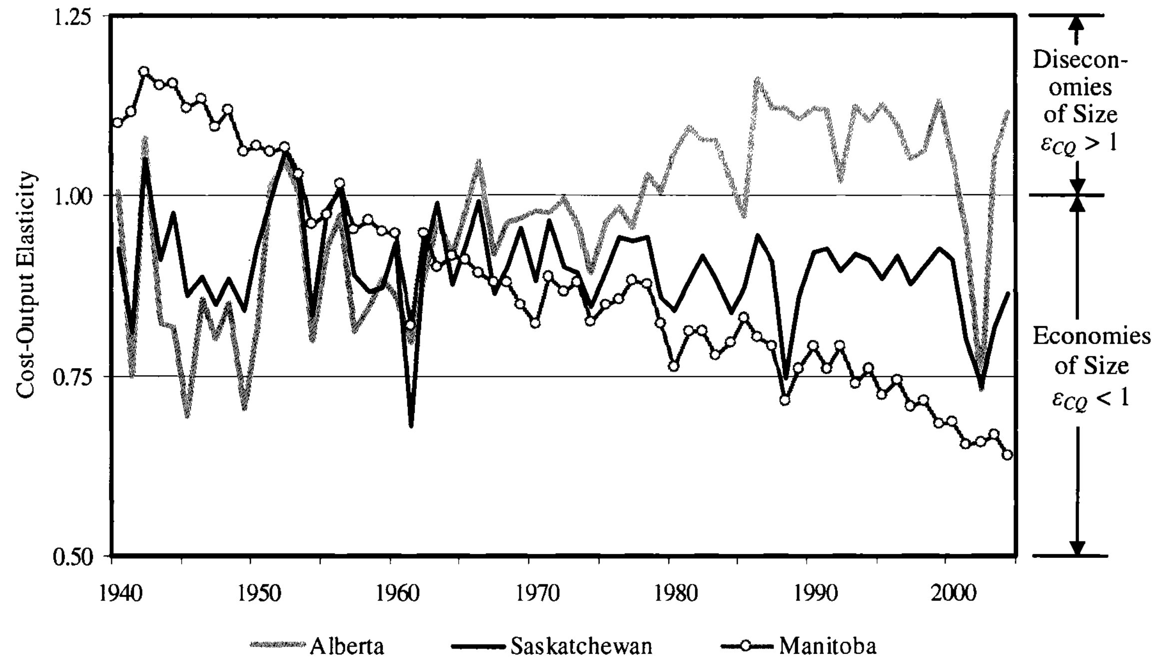
technical change are explored along with relevant measures of the production structure in Sections 6.3.1 and 6.3.2.

6.3.1 Cost-Output Elasticities and Returns to Scale

An economically significant measure of production structure that can be obtained from the estimated translog cost functions are economies of size and therefore returns to scale. Cost-output elasticity (ε_{CQ}) is the reciprocal of elasticity of size. $\varepsilon_{CQ} < 1$ indicates economies of size, while $\varepsilon_{CQ} > 1$ specifies diseconomies of size. At cost minimizing points, economies of size imply the presence of increasing returns to scale (a positive component of productivity growth), while diseconomies of size imply decreasing returns to scale (a negative component of productivity growth) (Chambers, 1988). In Table 6.1 increasing returns to scale are apparent over the 1940 to 2004 period, since in every sub-period scale effects are a positive component of productivity growth. However, it is possible that this long time-span has been characterized by periods of both increasing and decreasing returns to scale in livestock and crops production (with the overall result being increasing returns to scale). In Figures 6.1 and 6.2 the cost-output elasticities at each sample point are plotted.

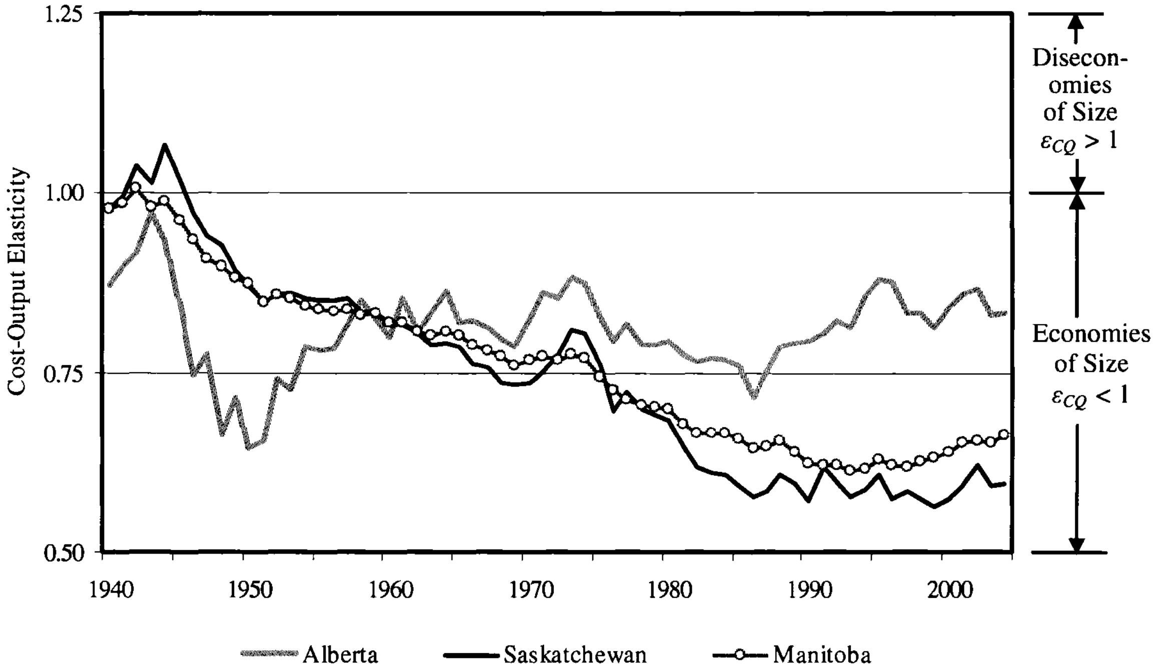
The cost-output elasticity trends for crops in the three provinces are very different. Alberta crops' cost-output elasticity increases over the entire sample becoming greater than unity over the last twenty-five years. The implication is that over the first forty years of the sample, crops farming exhibits increasing returns to scale though the returns to scale decrease over time. However, from the eighties onward, Alberta crops farming is characterized by decreasing returns to scale. Manitoba crops farming, on the other hand, displays a declining cost-output elasticity over time; decreasing returns to scale are present for the first fifteen years, but from the early 1950s onward Manitoba crops display increasing returns to scale that grow considerably over time. Unlike Alberta and Manitoba, Saskatchewan crops farming exhibits a relatively constant level of increasing returns to scale over time. The respective provinces' cost-output elasticities indicate that the level of aggregate crop output in each province has had different impacts on each province's productivity growth at different points in time, at least to the extent that scale effects make up an economically significant portion of productivity growth.

Figure 6.1 Crops Cost-Output Elasticities, Prairie Provinces, 1940-2004



Provincial livestock cost-output elasticities display much more commonality than is the case with crops. All three provinces exhibit declining cost-output elasticities over time. The cost-output elasticities are also, with the exception of a couple of data points, less than unity implying increasing returns to scale. Alberta's cost-output elasticity declines rapidly from the mid-forties to 1950 then increases over the decade and remains at a fairly constant level of increasing returns to scale for the final forty-five years (1959-2004). Manitoba and Saskatchewan display declining cost-out elasticities over a much longer period – from 1945 to 1990. From 1990 onward the cost-output elasticities remain relatively constant at a level of increasing returns to scale significantly higher than Alberta's.

Figure 6.2 Livestock Cost-Output Elasticities, Prairie Provinces, 1940-2004

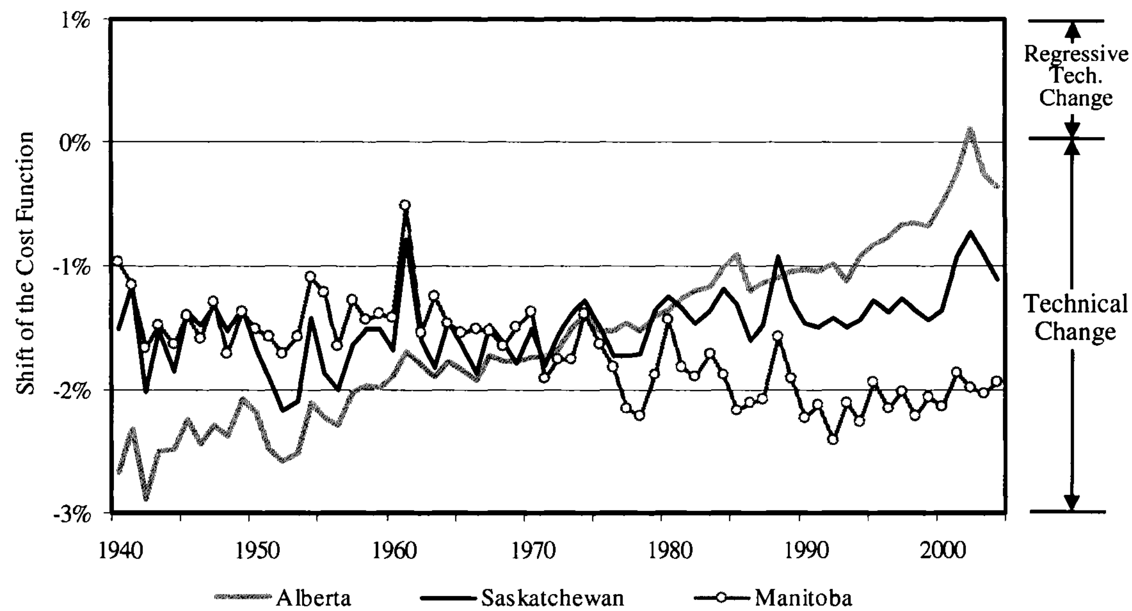


6.3.2 Shift in the Cost Function and Technical Change

Technical change, as represented by downward shifts in the cost function, can also be derived from the estimated cost functions and displayed graphically. Interpretation of the graphs is somewhat counterintuitive: a negative proportionate shift in the cost function implies positive technical change while a positive shift indicates regressive technical change. Figures 6.3 and 6.4 illustrate the proportionate shift in the cost function at each data point.

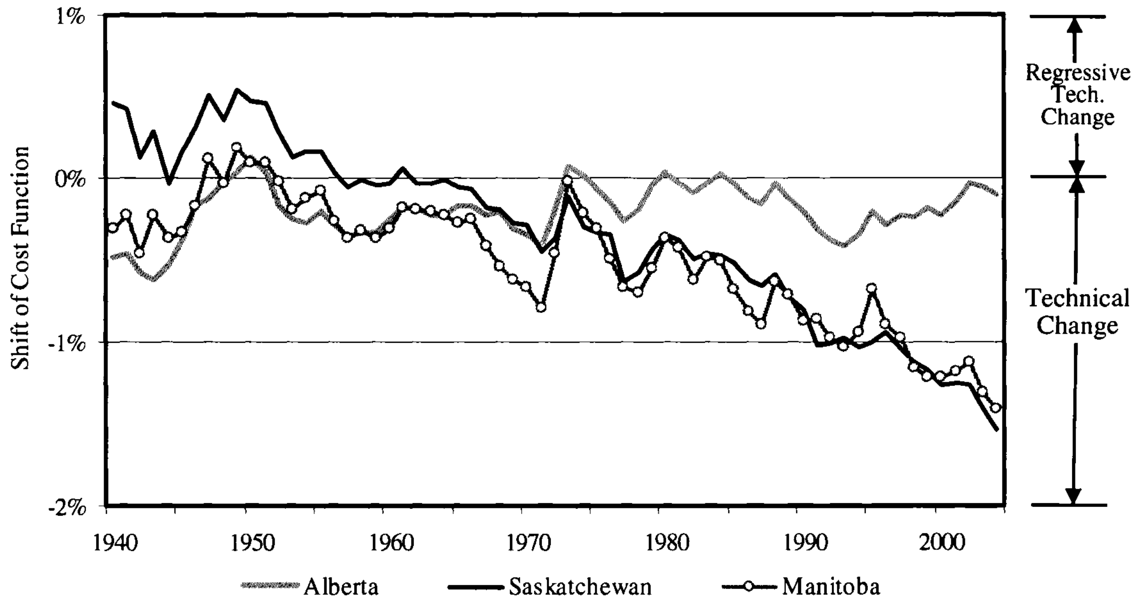
From Figure 6.3 it is apparent that the crops cost functions for all three provinces shift downward for the entire sample with the exception of a single data point; this implies that the impact of technical change has been overwhelmingly positive for crops farming. Technical change, although positive in Alberta crops, declines markedly over time. Over the first thirty years Alberta crops display the most rapid technical change. However, from 1970 to 2004, the pace of technical change in Alberta crops slows and becomes stagnant relative to the rates of technical change reported for Saskatchewan and Manitoba crops. Technical change for Manitoba crops has increased at a reasonably stable pace over the entire period, and by the late 1970s Manitoba is recording the most rapid technical change of the three provinces. Technical change is comparatively steady in Saskatchewan for the first forty years, and thereafter deteriorates moderately.

Figure 6.3 Crops Cost Function Shift, Prairie Provinces, 1940-2004



Technical change in livestock (Figure 6.4) is marked by two general trends: first, Alberta exhibits a slow rate of technical change, which, although typically positive, progresses at only a modest level; second, the rate of technical change in Saskatchewan and Manitoba increases over time. For the first fifteen years Saskatchewan livestock displays regressive technical change, yet it advances over time, and by the mid-seventies Saskatchewan's rate of technical change is on par with Manitoba's. Overall, Manitoba livestock presents the most rapid technical change, which advances steadily over time.

Figure 6.4 Livestock Cost Function Shift, Prairie Provinces, 1940-2004



6.3.3 Implications of Technical Change and Returns to Scale for Productivity Growth

Figures 6.1 through 6.4 and their related summaries relay the detail that permits an accurate assessment of the changes in productivity growth (presented graphically in Figures 5.3 through 5.8). The ensuing analysis synthesizes the findings of the preceding Section with the TFP growth estimates of Chapter 5 to examine how productivity growth has occurred in crops and livestock agriculture in each province and in the Prairies.

6.3.3.1 Alberta

Alberta crops productivity growth is relatively slow in comparison with Saskatchewan and Manitoba. It is also marked by a distinct decline in TFP growth from 1994 to 2004 (-0.33 percent per annum). From Figures 6.1 and 6.3, two phenomena can be seen to contribute to the pattern of Alberta crops TFP growth: first, technical change deteriorates over the entire sample, but particularly over the last ten years, where it is even regressive at a sample point (2002), albeit a drought year; second, the returns to scale in the Alberta crops sector are relatively low and over the last thirty years indicate decreasing returns to scale. The decomposition of TFP growth in Section 6.2 showed that scale effects play a relatively small role in Alberta crops TFP. Therefore, the key to lagging TFP growth in Alberta crops is the declining rate of technical change.

Section 6.2 indicated that scale impacts play the dominant role in Alberta livestock TFP growth, with technical change playing a strong, yet secondary, role. From Figures 6.2 and 6.4 lower relative TFP growth for Alberta livestock is anticipated, since, in terms of returns to scale and measured technical change, it performs poorly relative to the two other Prairie provinces. Therefore, both mediocre returns to scale and sluggish technical change are responsible for the slow productivity growth apparent in Alberta livestock.

6.3.3.2 Saskatchewan

Saskatchewan crops productivity growth exceeds Alberta's. Nevertheless, it also slows appreciably from 1994 to 2004. Technical change is the dominant component of TFP growth for Saskatchewan crops, although scale effects also play a role. Figure 6.3 indicates that the rate of technical change declines moderately for Saskatchewan crops from the early nineties onward, overwhelming its strong returns to scale during this period and leading to middling productivity growth performance.

Saskatchewan livestock productivity growth is marked by a period of negative TFP growth (-0.39 percent) from 1940 to 1959 and extremely rapid TFP growth of 4.28 percent per annum from 1994 to 2004. The roles of scale effects and technical change offer a convincing explanation for these two dissimilar findings: over the first twenty years there exists a moderate level of increasing returns to scale, but regressive technical change over much of this period erodes any productivity gains resulting from the returns to scale; in contrast, over the last twenty years Saskatchewan livestock displays the Prairies' highest returns to scale and rate of technical change, both of which contribute to the dramatic advance in livestock productivity growth.

6.3.3.3 Manitoba

Manitoba's productivity growth in both crops and livestock are substantially higher, over the entire 1940-2004 period, than the rates reported for Alberta and

Saskatchewan. However, over the first twenty years Manitoba agricultural productivity growth is much more modest: from 1940-1959 Manitoba crops posts the slowest productivity growth rate of the three Prairie provinces; Manitoba livestock's productivity growth from 1940-1959, although higher than Saskatchewan's, is lower than Alberta livestock's TFP growth. An inspection of Figures 6.1 through 6.4 points to the reasons for the higher overall TFP growth in Manitoba crops and livestock, yet slower growth over the first twenty years.

For Manitoba crops technical change is the dominant component of its productivity growth, with returns to scale playing a smaller role. Figure 6.3 shows that over the first twenty-five years technical change in Manitoba crops is weak relative to the other two provinces. Technical change, however, grows steadily over the sixty-five years, resulting in strong crops productivity growth over the final forty years. Returns to scale display similar trends; over the first twenty years they display decreasing returns to scale yet improve considerably over the entire sample to demonstrate substantial increasing returns to scale from 1970 onward.

Manitoba livestock TFP growth is strongly influenced by technical change, with a smaller role reserved for returns to scale. From Figures 6.2 and 6.4 it can be noted that both the rate of technical change and returns to scale are modest for Manitoba livestock during the first twenty years, but improve steadily over time and result in the strong productivity growth apparent in Manitoba livestock from 1980 to 2004.

6.3.3.4 Prairies

Not surprisingly, the dynamics of technical change and returns to scale in the Prairies echo the results reported for the individual provinces. Figures 6.5 and 6.6 illustrate how crops productivity growth has outpaced livestock productivity growth over the entire period. However, over the last twenty years productivity growth in the former has slowed and productivity growth in the latter has increased.

Prairie crops have enjoyed reasonably steadily increasing returns to scale from 1940 to 2004; nonetheless, technical change is the dominant component of productivity growth in crops, and, as Figure 6.5 illustrates, technical change has deteriorated over time, resulting in the productivity growth slowdown apparent in Prairie crops.

The relatively slow growth in livestock productivity can be explained by the extremely low relative rate of technical change present in Prairie livestock (Figure 6.6). The productivity growth realized by Prairie livestock, particularly towards the end of the sample, can be ascribed to its strong growth in returns to scale, since scale effects play a prominent role in its TFP growth (Table 6.1).

Figure 6.5 Crops Cost-Output Elasticity and Cost Function Shift, Prairies, 1940-2004

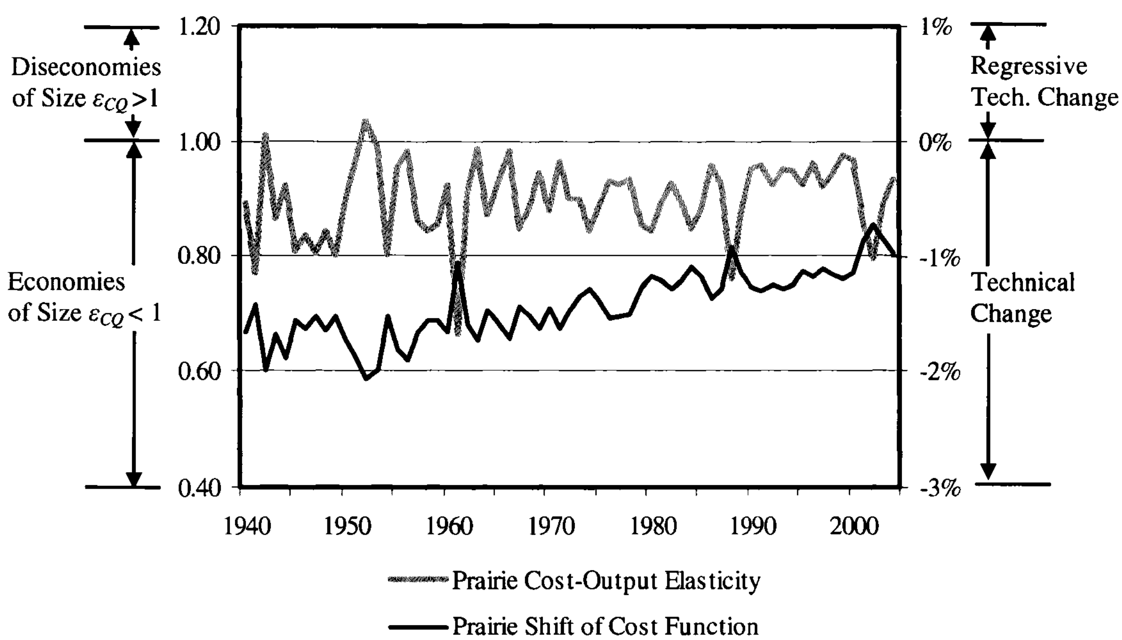
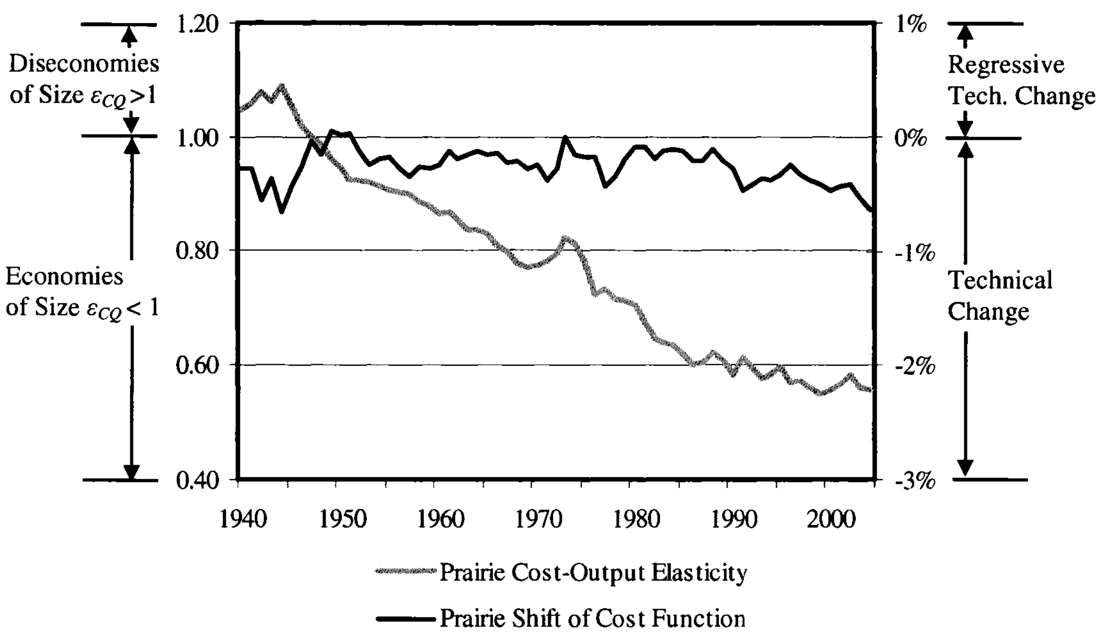


Figure 6.6 Livestock Cost-Output Elasticity and Cost Function Shift, Prairies, 1940-2004



6.4 Further Measures of Production Structure

The importance of technical change and economies of scale in shaping productivity growth in Prairie agriculture is apparent from Section 6.4. Therefore, it is instructive to assess two additional measures of Prairie agriculture's production structure that can provide additional insight into technical change and scale effects. The first measure to be considered is economies of scope

6.4.1 Economies of Scope

The analysis of agriculture in this study operates largely under the assumption that crops and livestock activities can be successfully disaggregated and assessed separately. Nevertheless, in the Prairie provinces both livestock and crops activities occur and the resulting (dis)economies of scope will have an impact on aggregate productivity growth.

Following Murray and White (1983) economies of scope are present if equation (6.10), derived from the translog cost function equation (6.4), is satisfied:

$$(6.10) \quad \frac{\partial^2 C}{\partial Q_1 \partial Q_2} \approx \alpha_1\alpha_2 + \delta_{12} < 0$$

Table 6.3 presents the results of equation (6.10). The values for the Prairies and all three provinces are positive, and all but Manitoba are statistically significant at the one percent level. The results imply diseconomies of scope in Prairie agriculture.[7] To the extent that the finding of diseconomies of scope is correct, Prairie provinces can achieve increased returns to scale in agriculture by specializing in either livestock or crops.

The findings of diseconomies of scope is a somewhat esoteric result, since its interpretation at the aggregate level is different than at the firm level (see Section 3.4.1). Nonetheless, the measure does indicate that the production of crops and livestock at the aggregate level is not complementary in nature, in so far as returns to scale are concerned. Determining why this is the case remains an open question. It may be that crops and livestock agriculture compete in terms of the timing of operations and human capital and managerial expertise. As a consequence, output expansion in one activity has a negative impact on output expansion in the other.

Table 6.3 Economies of Scope in Prairie Agriculture, 1940-2004

	Prairies	Alberta	Saskatchewan	Manitoba
$\alpha_1\alpha_2 + \delta_{12}$	0.0928**	0.1855**	0.1173**	0.0193

** denotes statistical significance at the one percent level.

6.4.1 Bias of Technical Change

Table 6.1 indicates that technical change plays a prominent role in the productivity growth of crops and livestock in each of the provinces. A measure that can be derived from the estimated cost functions is the bias of technical change as described in Section 3.5. Determining the bias of technical change permits a more detailed

---

[7] Kim (1986) points out, however, that the results of equation (6.10) hold only at the point of approximation, consequently, the findings of diseconomies of scope should be interpreted with caution.

assessment of how technical change occurs and how it varies in crops and livestock farming and in the different provinces. Formally, the bias in technical change can be derived from equation (6.2), and written as:

$$(6.11) \quad B_i = \frac{\partial \ln S_i}{\partial T} \qquad i = 1,..,4$$

Table 6.4 reports the bias of technical change. Twenty-eight of the thirty-two estimates of biased technical change are statistically significant at the one percent level. A number of economically significant trends are discernible from the results. First, technical change is strongly biased towards the use of the materials input across all the provinces; this is an indication of the changing nature of agriculture with an increased reliance on fuel, pesticides and fertilizer in crops farming and fuel and vet expenditures in livestock. Technical change is also strongly labour saving, and weakly biased towards the use of land and capital (with the exception of it being capital saving for Alberta crops). The bias away from labour is a reasonable finding, since agriculture in developed nations has been characterized by lower labour intensities per unit of output over time. Typically, technical change in Prairie agriculture would be expected to be strongly capital using and land saving. The weaker estimates presented in Table 6.4 may be a result of the allocation of inputs used in this study. Buildings are considered as part of the land input rather than the capital input, thus the capital bias of technical change will be lower while the land bias will be higher.

The strongest biases are reported in Manitoba agriculture (away from labour and towards materials). It is plausible that Manitoba's use of their material and labour inputs permit it to realize more rapid rates of technical change, likely due to biochemical and mechanical innovations, and hence superior productivity growth. Alternatively, the direction of causation may flow in the opposite direction; the type of technical change occurring in Manitoba may determine the relative input usage. No matter the direction of causation, it is evident that accumulation of materials and decline in labour use are intertwined with higher rates of technical change in Prairie agriculture.[8]

Table 6.4 The Bias of Technical Change in Prairie Agriculture, 1940-2004

		Capital B_1	Land B_2	Labour B_3	Materials B_4
Alberta	Crops	-0.0019**	0.0007**	-0.0049**	0.0061**
	Livestock	0.0012**	0.0008**	-0.0077**	0.0058**
Saskatchewan	Crops	0.0002	0.0012**	-0.0083**	0.0069**
	Livestock	0.0005	0.0009**	-0.0070**	0.0056**
Manitoba	Crops	0.0017**	0.0017**	-0.0107**	0.0074**
	Livestock	0.0009**	0.0001	-0.0088**	0.0078**
Prairies	Crops	-0.0016**	0.0023**	-0.0047**	0.0040**
	Livestock	0.0022**	0.0002	-0.0084**	0.0061**

** denotes statistical significance at the one percent level.

6.5 Summary

Throughout Chapter 6 a variety of measures are presented that explain how the productivity growth reported in Chapter 5 occurs. The findings in Chapter 6 form the basis to begin answering the four questions posed at the end of Section 5.2.4.

1. *What accounts for the lower productivity growth rates in livestock farming relative to crops?*

   The lower productivity growth rates in livestock farming are a result of the slower rate of technical change occurring in livestock, relative to crops. The implication is that the crops sector has been better able to adopt or generate technological advances.

[8] It appears that, in general, the absolute values of the biases of Saskatchewan's technical change fit between Manitoba and Alberta's, though somewhat closer to the values reported for Alberta.

2. *Why has livestock productivity growth accelerated considerably over the past twenty-five years in Saskatchewan and Manitoba, while only moderately in Alberta?*

   In Saskatchewan and Manitoba livestock the rate of technical change increases during this period, as do the returns to scale. In contrast, the returns to scale and rate of technical change in Alberta livestock remain relatively stagnant over the last twenty-five years; the result is only moderate productivity growth, in comparison to the high rates of livestock productivity growth recorded in Saskatchewan and Manitoba.

3. *Why has crops productivity growth slowed in Alberta and Saskatchewan from 1994 to 2004, and increased in Manitoba over the same period?*

   In Alberta and Saskatchewan the rate of technical change slows over the last eleven years in crops farming. In Manitoba, over the same period, the rate of technical change has been relatively steady.

4. *Why are both crops and livestock productivity growth rates somewhat higher in Saskatchewan than in Alberta, and considerably higher in Manitoba?*

   In both crops and livestock Manitoba typically exhibits higher rates of technical change and returns to scale, the two principal components of productivity growth. Saskatchewan crops and livestock display, in general, rates of technical change and returns to scale, that are superior to Alberta's yet weaker than Manitoba's.

The foregoing answers offer some direction, yet they are incomplete. What remains is to assess the factors responsible for measured rates of technical change and returns to scale, so that the causes of productivity growth can be effectively determined and viable policy options entertained. In Chapter 7, the probable causal factors underpinning measured TFP growth are evaluated.

CHAPTER 7: CAUSAL ANALYSIS OF PRODUCTIVITY GROWTH

7.1 Introduction

A number of causal explanations for the recorded productivity growth and its variation are evaluated in Chapter 7. Two approaches are taken in assessing the determinants of productivity growth. First, a qualitative approach is used to present a broad based description and evaluation of the potential causes of the productivity growth in Prairie agriculture. Second, a number of the qualitative explanations arrived at are quantified and formally tested in an econometric model. A synthesis of the findings from both approaches is presented at the end of the Chapter.

The causal analysis in this Chapter focuses specifically on productivity growth in Prairie agriculture for two reasons. First, the Prairies are a relatively homogeneous region in terms of agricultural inputs and outputs, relative to agricultural production taking place in other Canadian provinces. Thus, it is anticipated that there are causal explanations related specifically to Prairie agriculture, and as well that substantive commonality exists in the causal explanations relating to the three Prairie provinces. Second, Prairie agriculture is considered distinct enough in character from other regions in Canada, the United States, and elsewhere, that it is not appropriate to adopt a one-size-fits-all explanation for the determinants of agricultural productivity growth.

7.2 Qualitative Evaluation of Factors Responsible for Productivity Growth

The advantage of pursuing a qualitative approach in assessing the factors underpinning productivity growth is two-fold. First of all, a number of important factors that are not amenable to quantification and econometric modeling can be considered. Second, the qualitative approach provides the basis for the ensuing quantitative econometric approach.

Determining the origins and causes of technological advance is a difficult and most likely an impossible task. As such, it is not surprising that unraveling the story of productivity growth is at least as complicated, since productivity growth is composed of technical change (technology), *and* scale effects and changes in efficiency.[1] Nonetheless, it is possible to compile a list of plausible explanations for productivity growth in the context of Prairie agriculture. The list presented in Table 7.1 is not exhaustive, yet it contains the most reasonable explanations for Prairie agricultural productivity growth and its variation over time, between crops and livestock, and among provinces. The list provides a starting point for assessing the causes of the agricultural productivity growth in the Prairies.

Sections 7.2.1 through 7.2.7 develop in greater detail the explanations listed in Table 7.1. Where applicable, data offering insight into the qualitative explanations are presented. Much of the data are used in the econometric model of Section 7.3. Except where otherwise noted the data presented are derived from Statistics Canada sources.

Table 7.1 Causes of Prairie Agricultural Productivity Growth and Variation, 1940-2004

Section	Cause
7.2.1	Research and development expenditures.
7.2.2	Education and extension expenditures.
7.2.3	Terms of trade.
7.2.4	Inherent biological and production process related productivity differences.
7.2.5	Geoclimatic differences between provinces.
7.2.6	Government policy (i.e. producer support and other programs)
7.2.7	Structural change: farm size, specialization, and off-farm labour rates.
7.2.8	Regional economic conditions and financial pressures.

[1] To emphasize the difficulties in determining the causes of productivity growth, productivity growth or the residual in growth accounting has been famously referred to as "some sort of measure of ignorance" by Abramovitz (1956).

7.2.1 Research and Development

Griliches' (1958) classic study of the adoption of hybrid corn varieties in the U.S. is the first in a succession of studies evaluating the social returns to agricultural research and development (R&D). The vast majority of studies find substantial rates of return from agricultural R&D expenditures. Alston and Pardey (2001) review 1,772 studies and find average annual percentage rates of return of 98.2 and 60.1 percent from agricultural R&D expenditures for developed and developing nations respectively. Large returns to R&D are also found for Canadian agriculture (e.g. Fox *et al*, 1990; Widmer *et al*, 1988; Huot *et al*, 1989). Strictly speaking, high rates of return to R&D expenditures do not need to be associated with productivity growth, since the rates of return are derived from the changes in agricultural output supply. However, practically speaking, in a sector that derives the majority of its output growth from productivity growth, high rates of return can be ascribed in large part to the productivity growth arising from R&D expenditures. In this sense, rate of return studies can be regarded as implicitly supporting the relationship between R&D expenditures and productivity growth.

Empirical studies that explicitly evaluate the relationship between R&D expenditures and productivity growth are not as common as the implicit productivity R&D studies reviewed above. Nonetheless, a number of leading economists (e.g. Ruttan, 2002; Huffman and Evenson, 1993; Antle and Capalbo, 1988) have clearly articulated the importance of R&D to agricultural productivity growth. Moreover, empirical studies by Brinkman (1984) for Canadian agriculture and Huffman and Evenson (1993, 2001) for U.S. agriculture show that R&D expenditures have a considerable impact on agricultural productivity growth.[2]

The foregoing discussion indicates that R&D expenditures should occupy a central role in any explanation of productivity growth in Prairie agriculture; and perhaps that the variation in R&D expenditures can account for a considerable portion of the variation in productivity growth. However, prior to examining Prairie R&D and its role in generating productivity growth two issues should be addressed. First, the path from R&D expenditures, to technological advance, through to productivity growth is a

---

[2] Griliches and Lichtenberg (1984) also find a strong empirical relationship between R&D expenditures and productivity growth for a number of non-agricultural industries.

complex process. Second, the determination of R&D expenditures is rarely a straightforward procedure.

7.2.1.1 Accounting for Research and Development Expenditures

The first complication in measuring R&D is encountered when attempting to discern what constitutes R&D. It is obvious that experimental work conducted at agricultural research stations should be included. However, it is equally true that developments in basic sciences (e.g. physics or economics) often precede developments in applied science (e.g. soil science or marketing) and should be counted. Arriving at measures of expenditure that accurately capture the entire R&D system is not a trivial task.

A second complication is that public (both federal and provincial) and private R&D expenditures need to be considered. Records concerning public R&D expenditures are limited, particularly for more distant time periods. In many respects it is even more challenging to arrive at accurate R&D expenditures for private sector firms.

Third, much R&D is not conducted in the geographic area where the productivity growth results accrue. For example, increased horsepower would be anticipated to have a substantive impact on Prairie crops productivity. However, the majority of R&D in this area occurs outside the Prairies; this is an instance of R&D spill-ins. Accounting for public and private R&D spill-ins (and spill-outs for that matter) is challenging.

Fourth, allocation of R&D expenditures is rarely straightforward. Research expenditures are often available only in very aggregate measures, thus allocating expenditures between specific agricultural outputs and regions is difficult.

A final issue in R&D measurement is the choice of an appropriate lag structure that reflects the returns from the investment over time. The total return to any R&D expenditure will typically take place over a number of years.[3] The specific lag structure of an R&D investment will vary depending on the time required for the development of technologies and their subsequent adoption by producers. Figure 7.1 illustrates two potential lag structures for an R&D investment. Lag 'a' illustrates an investment that has

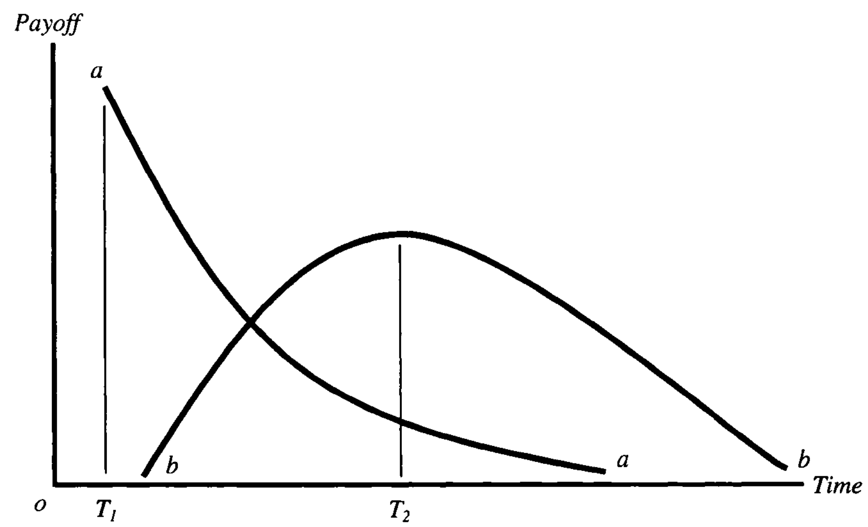
---

[3] It has become common in empirical studies to use lags of upwards of thirty years (Huffman and Evenson, 1993, 2001; Alston and Pardey, 2001).

a very high early payoff, but whose return declines relatively rapidly thereafter. Lag 'b' depicts an investment that increases in payoff over time until it reaches a maximum and then declines.

Different R&D investments have different lag structures (e.g. R&D investments in farm machinery compared with crop genetics). However, conceptually, it is possible to view aggregate R&D expenditures as a stock from which technological innovations are developed (Huffman and Evenson, 1993, 2001; Alston and Pardey, 2001; Mullen and Crean, 2006). This is the approach used in this study and can be seen in the representations of R&D expenditure stocks for Prairie crops and livestock (see Figure 7.2, Section 7.2.1.2).[4]

Figure 7.1 Research and Development Lag Structures



[4] Alternatively, a flexible lag structure (e.g. an Almon lag) can be used where annual R&D expenditures are lagged (e.g. Veeman and Fantino, 1985). For econometric reasons, specifically degrees of freedom limitations, the stock of R&D expenditures approach is used in this study.

7.2.1.2 Research and Development Expenditures in Prairie Agriculture

Figure 7.2 presents the stock of R&D expenditures for Prairie crops and livestock. A twenty year lag structure (seven rising + six constant + seven declining) is assumed for each year's R&D expenditure.[5] Each province's provincial R&D expenditures are calculated using annual reports of the respective departments of agriculture and related research institutes. For more distant data (i.e. 1945 through 1980) Brinkman's (1984) data are used. Federal expenditures are calculated using Government of Canada Public Accounts from 1920 to 1993 and Statistics Canada data from 1994 to 2005. Private sector expenditures are calculated using Brinkman's (1984) data for 1945 to 1980 and Statistics Canada data for 1994 to 2005. Missing values are interpolated and the allocation of expenditures between crops and livestock are based on Brinkman's (1984) and Fox *et al's* (1987) calculations. The allocation of federal and private R&D between provinces is based on their respective shares of agricultural cash receipts. All expenditures are in 1972 dollars (nominal expenditures deflated by the CPI).[6]

Two overarching trends can be discerned from Figure 7.2. First, the R&D expenditure stocks of both crops and livestock increase consistently before leveling off in the early 1990's and late 1980's respectively.[7] This finding may serve to explain the decline in crops productivity growth for Alberta and Saskatchewan from 1994 to 2004. However, it does not explain the rapid productivity growth in Manitoba crops over this same period. Moreover, Figure 6.5 indicates that the rate of technical change has been

---

[5] This a variation on the thirty-three year lag (seven rising + six constant + twenty declining) used by Huffman and Evenson (1993). The shorter lag structure is used for Prairie R&D due to superior fit and data limitations.

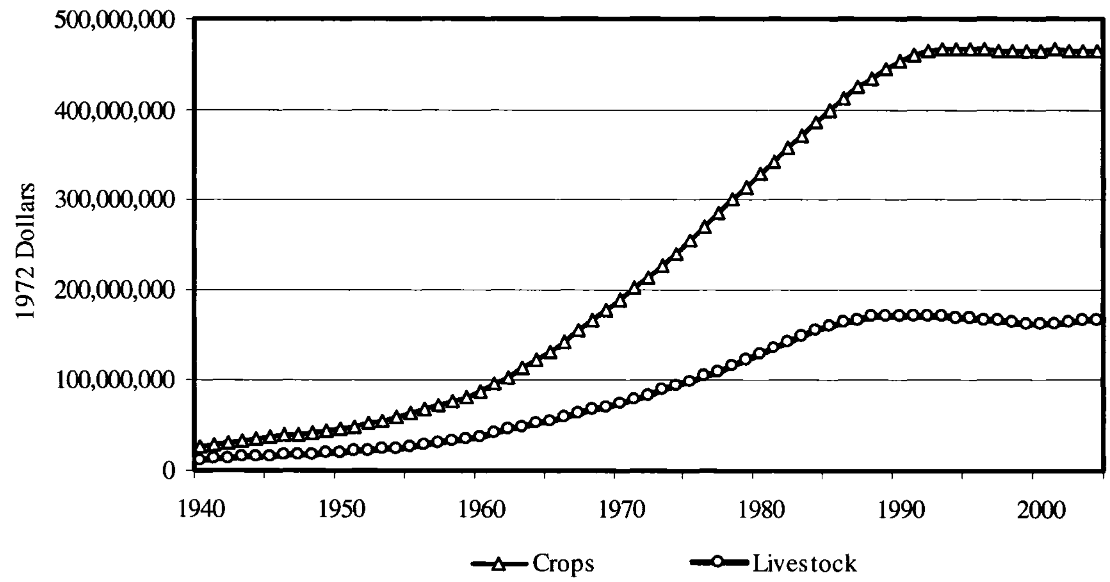
[6] To the extent possible, given time and data constraints, the concerns reviewed in Section 7.2.1.1 are integrated into the calculation of Prairie crops and livestock R&D expenditure stocks. Further refinements to the R&D data were not practicable (e.g. accounting for R&D spill-ins and spill-outs). Nonetheless, the data compiled present the broad trends in the stock of R&D over time, and provides important insight into the role of R&D in productivity growth.

[7] The leveling off of stocks of R&D expenditures in the 1990's is also found in Australian agriculture by Mullen and Crean (2006). In contrast, constant dollar stocks of overall U.S. public and private agricultural R&D exhibit much more consistent growth from 1940 through 2004 (calculated using data from Huffman and Evenson (1993) and the National Science Foundation and USDA Current Research Information System).

declining from 1950 onward, not beginning in the 1990's. Figure 7.2 also does not point to a substantive reason for the rapid productivity growth in Prairie livestock from 1980 to 2004. This may not be very significant due to the role of economies of scale in livestock productivity growth. However, technical change also plays an important role in livestock productivity growth; Figure 6.6 indicates increasing technical change for Prairie livestock from 1990 to 2004 which contrasts with the leveling off of the livestock R&D stock reported in Figure 7.2. The implication is that the realized technological advance for livestock during this period was not largely a result of domestic R&D expenditures.

The second trend apparent from Figure 7.2 is the considerably higher crop R&D stock relative to livestock. It is possible that lower R&D investments in livestock relative to crops may account in part for the lower productivity growth found in livestock. However, the greater investment in crops is somewhat overstated since some crops are inputs to livestock production (as feed). Some crops R&D investments should be attributed to both crops and livestock. R&D investments in livestock are also typically less geoclimatically sensitive in nature. This would suggest that R&D spill-ins are higher for livestock than for crops, which would inflate the livestock R&D stocks in Figure 7.2. For example, swine genetics from the southern United States could be integrated much more easily into Prairie livestock production than crop genetics from the same region.

Figure 7.2 Prairie Livestock and Crops R&D Expenditure Stocks (20 Year Lag in 1972 Dollars), 1940-2004



It appears unlikely that the changing stock of domestic R&D investments alone is a credible explanation for the recorded Prairie productivity growth rates. Nevertheless, it is not unreasonable to hypothesize that the stock of R&D investments results in a productivity growth baseline, and variations from this trend growth rate are the result of other influences. If this is the case, the leveling off of the Prairie R&D stock may potentially result in a long run decline in the trend productivity growth rates for both crops and livestock.[8]

---

[8] An argument can be made that a basic level of R&D expenditure is required to prevent productivity decline, rather than promote productivity growth. For instance, some level of R&D expenditure is required to combat evolving plant or animal diseases and prevent output and productivity decline (Townsend and Thirtle (2001) make this argument in the context of developing nation livestock research). It follows that the leveling off of the stock of Prairie R&D expenditures may serve to maintain past productivity advances, but will not promote productivity growth in the future.

7.2.2 Education and Extension

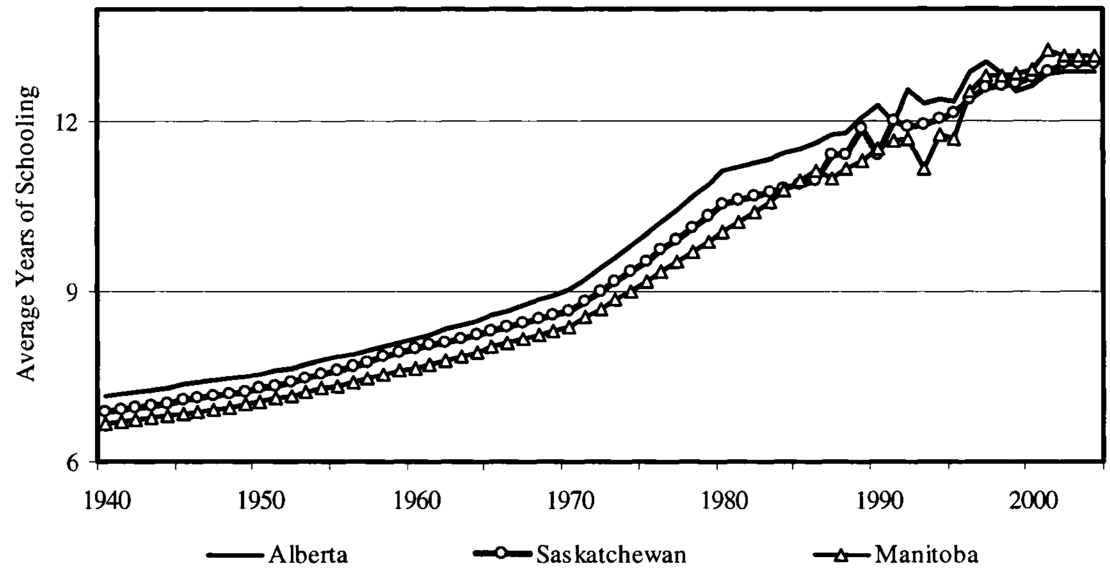
Education, a component of human capital, is traditionally viewed as an important source of productivity growth (Griliches, 1970). Education increases the quality of labour as producers can more effectively adopt and adapt to new technologies and changing conditions. Education also enhances producers' abilities to plan, analyze information and manage their businesses, skills that have become increasingly important in agricultural production over the last fifty years (Huffman and Evenson, 2001). Extension programs also increase producers' abilities to adopt novel technologies and improve management practices. It is anticipated that both factors play an important role in promoting agricultural productivity growth.[9]

Figure 7.3 displays provincial indexes of the years of producer schooling for agriculture in the three Prairie provinces. Years of schooling data are compiled from Census of Canada publications and Statistics Canada data files.[10] It is apparent from Figure 7.3 that levels of education have increased considerably over time in all three Prairie provinces. Clearly, improved producer education has played a considerable role in permitting many of the technological advances arising from the R&D expenditures detailed in Section 7.2.1 to be integrated into Prairie agricultural production. However, there is limited variation in education levels between provinces; as such, it is unlikely that education can explain differences in provincial agricultural productivity growth (i.e. Manitoba's higher level of productivity growth).

---

[9] Huffman and Evenson (1993) find this to be the case empirically for U.S. agriculture.
[10] Years of education for agricultural producers are not reported explicitly in either the Census of Canada or Statistics Canada data. For example, the 1940 Census reports ranges of years of education (e.g. 0-4 years, 5-8 years). In addition, the reported ranges vary between Censuses. Following Fox *et al*'s (1987) methodology, average years of education have been assigned to the different ranges to produce a representative series of provincial producer years of education.

Figure 7.3 Average Years Schooling: Alberta, Saskatchewan and Manitoba Agriculture, 1940-2004



Provincial public extension expenditures are presented in Figure 7.4. The data are derived from annual reports of the respective departments of agriculture and Brinkman's (1984) data for more distant points.[11] Following Huffman and Evenson (1993) the reported extension expenditures are calculated as having a three year total lag (.50 in period t, .25 in $t + 1$, .25 in $t + 2$). Real lagged extension expenditures drop off in the late 1970's for Saskatchewan and Manitoba, and in the late 1980's for Alberta.[12] The relationship between extension expenditures and productivity growth is not obvious from Figure 7.4. The decline in extension appears to have had different implications for crops

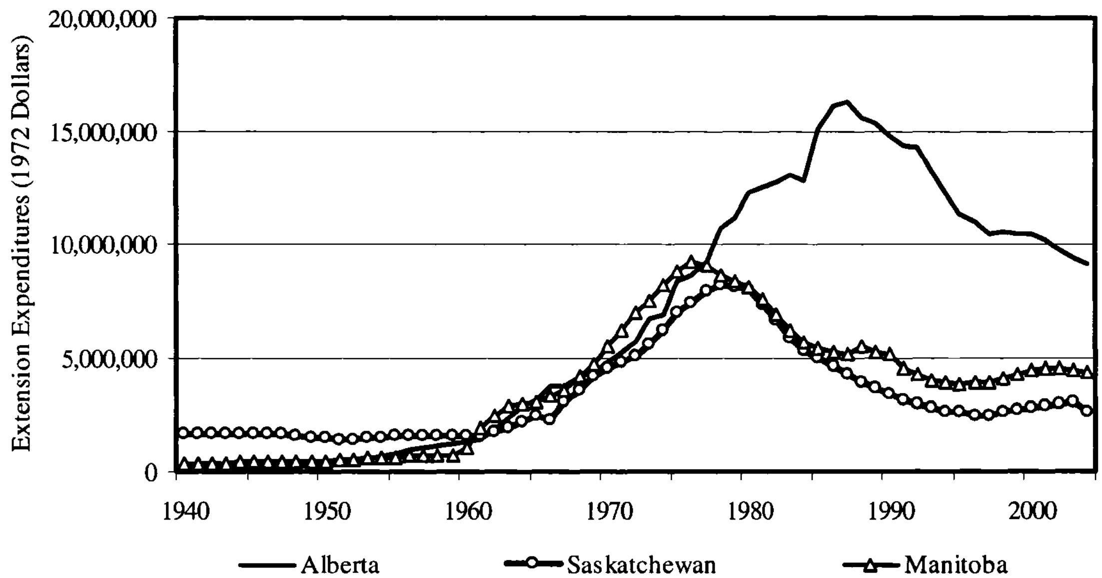
---

[11] It was not possible to apportion extension expenditures between crops and livestock. Furthermore, the distinction between R&D expenditures and extension is not always clear. Consequently, provincial extension expenditures may include some R&D expenditures and vice versa.

[12] Extension expenditures when measured on a per farm operator basis do not show as pronounced a drop off, since the number of farms in each province has declined over time. Yet the trends in extension expenditures for Saskatchewan and Manitoba in the 1970's and Alberta in the 1980's are persistent when calculated on a per capita basis. In addition, to a degree, extension activities are increasingly being performed in the private sector. Private sector extension expenditures are not included in Figure 7.4.

and livestock and the different provinces. However, the declining provincial extension programs in conjunction with the leveling off of the Prairie R&D stock may present concerns regarding future technological innovation and adoption in Prairie agriculture, and hence productivity growth.

Figure 7.4 Extension Expenditures: Alberta, Saskatchewan and Manitoba Agriculture (Three Year Lag in 1972 Dollars), 1940-2004



7.2.3 Terms of Trade

As illustrated in Section 5.1.1, the terms of trade provide a crude measure of the cost price pressures (i.e. growth in output prices minus the growth in input prices) facing agriculture. Tables 5.2, 5.3, 5.4 indicate that the terms of trade are generally much poorer (i.e. more negative) for crops than livestock in each of the Prairie provinces. The terms of trade may be worse in crops due to the competitive world market for grains and inventory management. Relative to crops, livestock prices are likely, in general, higher due to the supply management of some outputs (e.g. poultry and dairy), and the regional or continental nature of trade for other outputs (e.g. swine and cattle).

If producers' responses to the cost price squeeze, that is the declining terms of trade, are to adopt new technologies and management strategies then this can help explain why crops have proven to be more productive than livestock over time. Cochrane's (1958) classic *treadmill theory* of agriculture lends credence to the view that producers adopt technologies in response to cost pressures. Basically, Cochrane's contention is that in order to increase their income, producer's adopt new technologies which lower their per unit production costs. However, the technologies adopted typically result in increased agricultural output. In aggregate, the increase in agricultural output places downward pressure on output prices. The cost price squeeze then reoccurs as output prices drop requiring further technological adoption by producers. This cycle of technological advance and cost price pressures is termed the agricultural treadmill by Cochrane. Empirically, findings by Veeman and Fantino (1985) for Prairie agriculture, for the 1961 to 1980 period, suggest that a negative relationship between terms of trade and productivity growth does in fact exist. Although almost fifty years old, Cochrane's treadmill theory offers a compelling explanation for some of the developments in Prairie agriculture over the 1940 to 2004 period.

7.2.4 Inherent Biological and Production Process Related Productivity Differences

Huffman and Evenson (1993) indicate that inherent productivity differences exist between different agricultural outputs for both biological and production related reasons. First of all, over time different agricultural outputs have realized different rates of genetic improvement for a variety of reasons. Crops have benefited from scientists working consistently to increase the genetic potential of seeds, and since a proportion of seeds are purchased annually by farmers these advances are integrated relatively rapidly into production. In contrast, the longer production cycle of cattle permits fewer genetic improvements, relative to crops, and poultry and swine. In addition, Huffman and Evenson point out that, prior to the widespread use of artificial insemination, genetic advances in beef cattle were achieved largely through crossbreeding by farmers, rather than the more productive genetic programming of scientists. Swine, poultry, and dairy, in contrast, have benefited from more controlled genetics than beef cattle.

Production processes also play a role in inherent productivity growth differences. Ceteris paribus controlled production conditions offer improved opportunities to achieve productivity growth. This is the case for poultry, swine and dairy which are produced increasingly in controlled large scale industrial type intensive livestock operations. Although cattle feedlots have increased dramatically in size over the past twenty years it is not the case that the production of cattle from cow calf operator through to finishing operation exhibits the level of control and mechanization found in the poultry, swine and dairy sectors.

From the inherently most productive agricultural output to least productive, Huffman and Evenson's (1993) ranking as it relates to Prairie agriculture is: crops, poultry, swine and dairy, and cattle. The foregoing analysis grossly simplifies what is in reality a complex discussion concerning the productivity growth inherent in different agricultural outputs. However, the essential conclusions are consistent with many of the trends found in Prairie agricultural productivity growth.

First, crops as the most inherently productive agricultural output is supported by its stronger recorded productivity growth relative to livestock. Lower productivity growth for cattle and higher productivity growth for swine is also supported, by the finding that Alberta livestock (dominated by cattle) is substantially less productive than Manitoba livestock, which has a large and rapidly growing hog sector. Nonetheless, the hypothesis of inherent productivity differences does not explain why livestock productivity growth in Saskatchewan grows much more rapidly from 1980 to 2004 (1.86 percent a year) than in Alberta (0.34 percent a year), since cattle comprises a similar proportion of livestock output in both Alberta and Saskatchewan.

7.2.5 Geoclimatic Differences

Huffman and Evenson (1993) point to geoclimatic differences playing an important role in agricultural productivity growth.[13] This is the case principally for crops, but has implications for livestock since some crops are inputs in livestock production and poor geoclimatic conditions limit grazing potential At a provincial level, geoclimatic conditions point to Manitoba having a decided advantage due to more fertile soil and greater heat units. 1980 work by the Canada West Foundation indicates that 52

[13] The importance of climate is substantiated empirically by Veeman and Fantino's (1985) finding of a significant correlation between weather and Prairie crops productivity growth (1961-1980).

percent of cultivated land in Manitoba is CLI class one or two, compared with only 35 and 39 percent in Saskatchewan and Alberta respectively. Provincial agro-climatic indexes based on soil and climate characteristics are also reported, with higher numbers signifying superior conditions. Manitoba is highest at 1.8, followed by Alberta at 1.5 and Saskatchewan at 1.4.[14]

Geoclimatic similarities with regard to Alberta and Saskatchewan offer a reasonable account for the overall similarities in their crops productivity growth. Moreover, the considerable geoclimatic advantages realized by Manitoba support its relatively strong productivity growth in crops, and to a lesser extent its superior livestock productivity growth. Unfortunately, geoclimatic differences do not offer a robust explanation for the productivity slowdown in crops over the last eleven years in Alberta and Saskatchewan or the acceleration in livestock productivity growth over the last twenty-five years in Saskatchewan and Manitoba.

7.2.6 Government Policy

Directly or indirectly government policy plays a considerable role in agricultural production in most countries. Canada is no exception. The impact of government policy on productivity is ambiguous. Policy that increases producer income can result in productivity growth if producers are better able to adopt technologies and management practices due to their stronger financial position. The opposite may also be true; producers may adopt technologies more rapidly to respond to increasingly competitive conditions and financial stresses. In this regard, government policy may retard productivity growth.

Four policies of considerable importance to the Prairie productivity growth story are reviewed. First of all, the supply managed Prairie poultry and dairy sectors undoubtedly have an impact on livestock productivity growth. If the enhanced producer returns from supply management support the adoption of more productive technologies, rather than simple cost minimization on the part of producers, then overall livestock productivity growth would be enhanced, though perhaps not greatly since the share of

---

[14] The Canada West Foundation (1980) data are somewhat dated. However, it is anticipated that changes in their findings over the last twenty-five years are limited.

supply managed industries in livestock output declines steadily from 1940 to 2004. (see Figure 4.2). The opposite is true if supply management limits the incentives for producers to adopt new technologies.[15]

A second policy of note is the Crow rate which was removed in 1995. Basically, the Crow rate subsidized rail shipment costs of grain from the Prairie provinces to export markets (CWF, 1980). The policy served to encourage grain farming in the Prairies (better returns due to low transportation costs) and livestock production in Eastern Canada (artificially low feed costs). The Crow rate's impact on productivity growth for Prairie crops is likely negative, although the magnitude of the effect is uncertain. In contrast, for Prairie livestock the removal of the Crow rate likely had considerable positive consequences for its productivity growth. The resulting lower prices for feed in the Prairies contributed to a rapid expansion in livestock output (i.e. cattle and swine) throughout the Prairie provinces. This output expansion caused productivity growth due to the substantial economies of scale for livestock present at the provincial level (see Figure 6.2). Productivity growth may also have followed from the adoption of new technologies as the swine and cattle industries expanded.

A third policy of importance for agricultural productivity growth in the Prairies is the 1989 Canada-U.S. Free Trade Agreement (FTA) and subsequent 1994 North American Free Trade Agreement (NAFTA). The ultimate impact of the free-trade policies on Prairie crops sector productivity growth is somewhat ambiguous. For the Prairie livestock sector, however, to the extent that the trade agreements resulted in the expansion of the Prairie livestock sector, substantive scale based productivity growth likely occurred.

The fourth policy, or more appropriately group of polices, that will be examined are direct program payments to producers.[16] Figure 7.5 presents the total producer

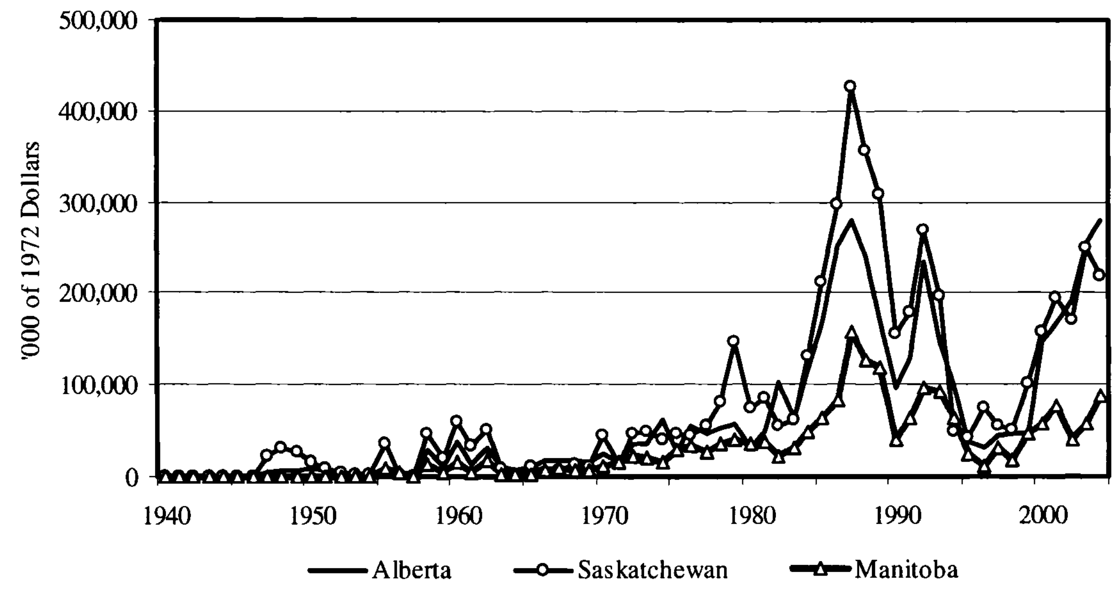
---

[15] Findings by Huffman and Evenson (2001) indicate that, in general, producer support programs in the U.S. are correlated with productivity growth. Whether this finding can be extended to Canada and the Prairies is an open question.

[16] Only direct producer payments were considered in this context (compiled from Statistics Canada Data). A variety of programs that impact market conditions and prices are not considered. Correspondingly, the impact of these programs on productivity growth understates the true impact of government support programs.

payments by province in 1972 dollars. There is no obvious correlation between producer payments and productivity growth in crops and livestock. However, if producer payments are responding to sudden crises (e.g. the drought years of the mid to late 1980's) they may promote technological adoption by stabilizing the position of producers, permitting longer term planning and reducing ratchet effects associated with rapid changes in farm income.

Figure 7.5 Direct Program Payments to Producers: Alberta, Saskatchewan and Manitoba, 1940-2004



The impact of government policy on productivity growth is ambiguous. It depends largely on producers responses to the programs – reducing financial stresses may encourage technology adoption or it may reduce producers' incentives to adopt technological advances. The removal of the Crow rate and the free trade agreements offer a convincing explanation for the acceleration in livestock productivity growth from the nineties onward. However, they do not suggest why productivity growth in Alberta livestock was much lower than the other two provinces from 1995 to 2004. Like many of the explanations already reviewed, government policies clearly play a role in productivity growth. However their impact in many cases is not obvious.

7.2.7 Structural Change

Substantial structural change has occurred in Prairie agriculture from 1940 to 2004. Prairie agriculture has been characterized by increasing farm sizes, specialization, and off-farm labour rates. The assumption adopted in this study is that structural change in agriculture is associated with superior economic returns accruing to producers. In this case it is probable that structural change also generates agricultural productivity growth. Huffman and Evenson (2001) find mixed evidence regarding the impact of structural change on U.S. agricultural productivity growth from 1953-1982. Farm size, specialization, and off-farm labour rates are all positively correlated with livestock productivity. However, U.S. crops productivity, while positively correlated to specialization, is negatively correlated with farm size and off-farm labour rates. Figures 7.6 through 7.10 illustrate measures of structural change for the Prairie provinces.

Figures 7.6 and 7.7 respectively show the increase in average farm size in crops and livestock for the Prairie provinces. Farm size is measured as the average output produced per farm in 1972 dollars.[17] The most obvious feature of Figures 7.6 and 7.7 is the rapid increase in average farm size for Manitoba crops and livestock from the 1990's onward, relative to Alberta and Saskatchewan. The larger average Manitoba crops farm size may help explain the considerable productivity growth the province has realized in crops from 1994 to 2004. Perhaps Manitoba crops farms have been able to leverage superior firm level returns to scale over this period, in relation to Alberta and Saskatchewan crops farms.[18] The story behind livestock is not as clear. Manitoba appears to benefit from its more rapid increase in average livestock farm size, with the highest livestock productivity growth rate of the Prairie provinces from the 1990's

---

[17] Farm size can also be calculated on the basis of average area or capital per farm; unfortunately, these two measures prove limited. Average area performs well for crops, but not for livestock, since intensive livestock operations do not require an extensive land base. Average capital per farm would be an ideal measure of farm size; however, it is difficult to deflate the nominal value of capital to arrive at a credible real value due to rapidly rising land prices. It is also the case that the measures of farm size are averages and thus obscure, to some extent, the changes with regard to the largest and smallest farms.

[18] Returns to scale at the firm level are not analogous to returns to scale at the aggregate level – see Section 3.4.1 for a more detailed discussion.

onward. However, the growth in average livestock farm size is similar for Alberta and Saskatchewan farms, and yet livestock productivity growth is considerably higher for Saskatchewan livestock from 1980 to 2004.

Figure 7.6 Average Crops Farm Size In Terms of Value of Production (1972 Dollars): Alberta, Saskatchewan, and Manitoba, 1940-2004

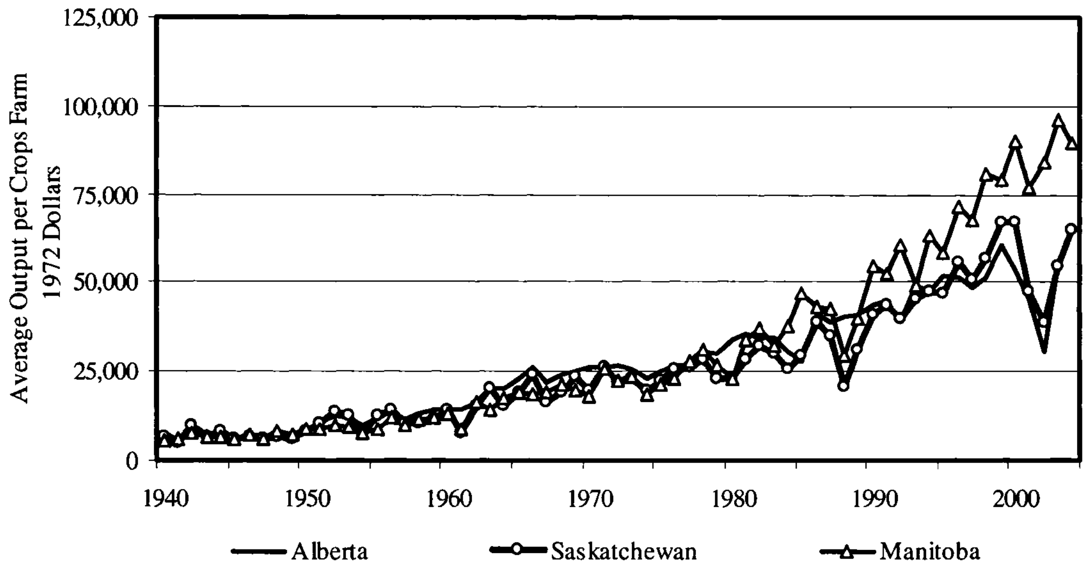
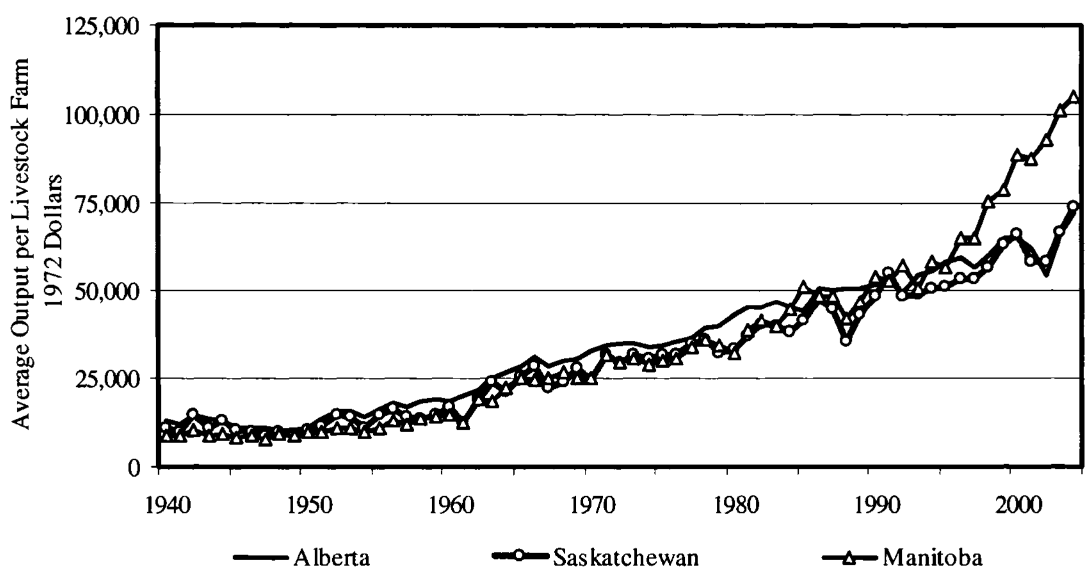


Figure 7.7 Average Livestock Farm Size In Terms of Value of Production (1972 Dollars): Alberta, Saskatchewan, and Manitoba, 1940-2004



Measures of output specialization are presented in Figures 7.8 and 7.9, calculated using Census of Agriculture data. Crop specialization measures the share of cropped land farmed by specialized crops farms. Livestock specialization measures the share of livestock in specialized livestock farms. According to this measure of specialization, livestock production has become considerably more specialized over time. Livestock specialization may help enhance productivity growth as management practices and technologies are more easily adopted and can focus on livestock production. Crops production, in contrast, does not exhibit any distinct trends in specialization. Although not overly sophisticated in their construction, these measures of specialization may point to a rationale for the accelerating productivity growth in the livestock sector over the last twenty-five years.

Figure 7.8 Share of Total Cropped Land Farmed by Specialized Crops Farms: Alberta, Saskatchewan, and Manitoba, 1940-2004

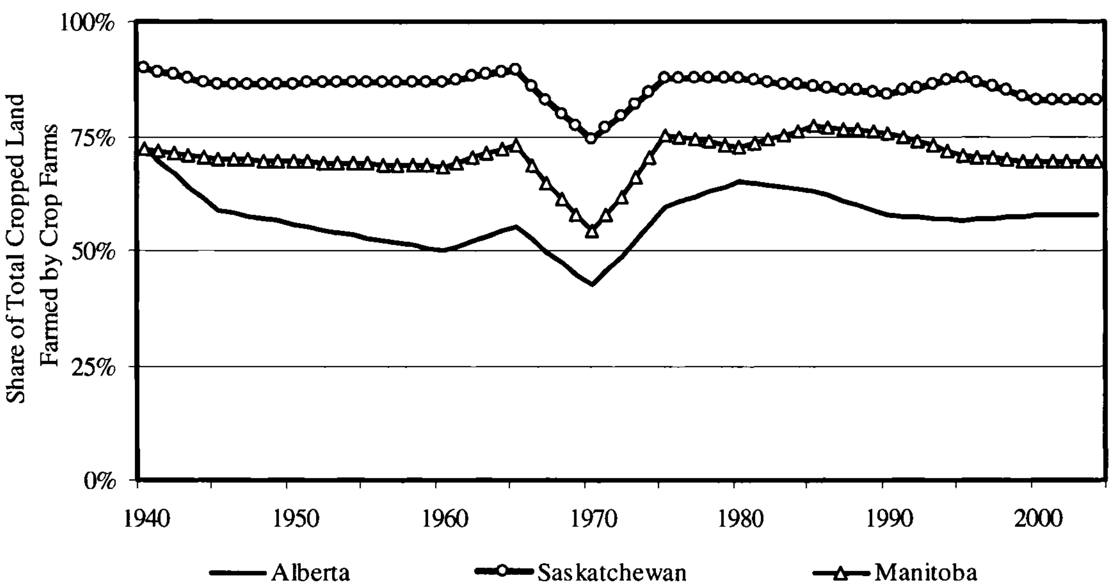
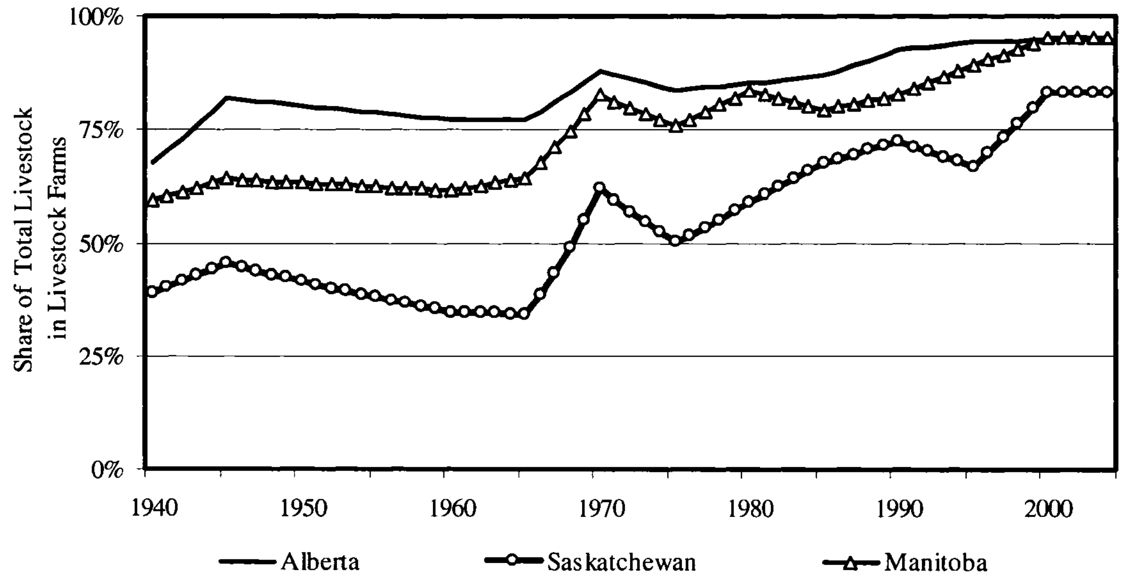
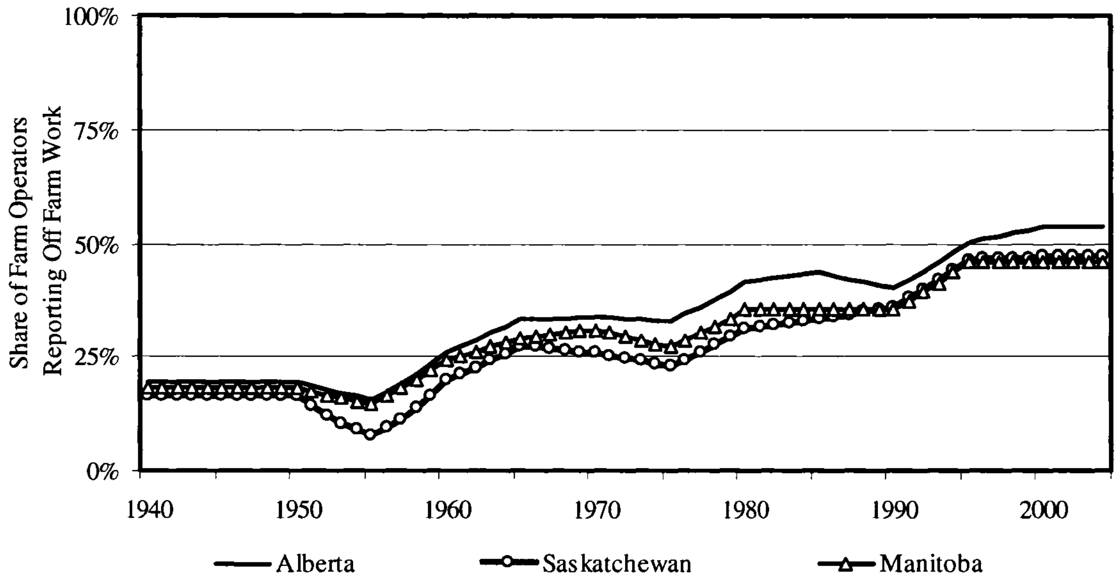


Figure 7.9 Share of Total Livestock in Specialized Livestock Farms: Alberta, Saskatchewan, and Manitoba, 1940-2004



Another indication of structural change is the share of farm operators reporting off-farm work. The effect that increased off-farm work has on agricultural productivity growth is unclear. Huffman and Evenson (2001) find a negative correlation between off-farm work and crops productivity growth, yet a positive correlation between off-farm work and livestock productivity growth (U.S. agriculture, 1953-1982). Increases in agricultural productivity may occur as less productive labour is drawn away from agriculture. Yet it can also be argued that off-farm work may attract the most productive and able farm operators. Figure 7.10, calculated from Census of agriculture data, indicates the increasing share of producers reporting off-farm work in the three Prairie provinces.

Figure 7.10 Share of Farm Operators Reporting Off-Farm Work: Alberta, Saskatchewan, and Manitoba, 1940-2004



The impact of the various facets of structural change on Prairie agricultural productivity growth is often ambiguous. Nonetheless, substantial structural change has occurred in Prairie agriculture, and structural change as a driver of economic growth is anticipated to play a vital role in productivity growth.

7.2.8 Regional Economic Conditions

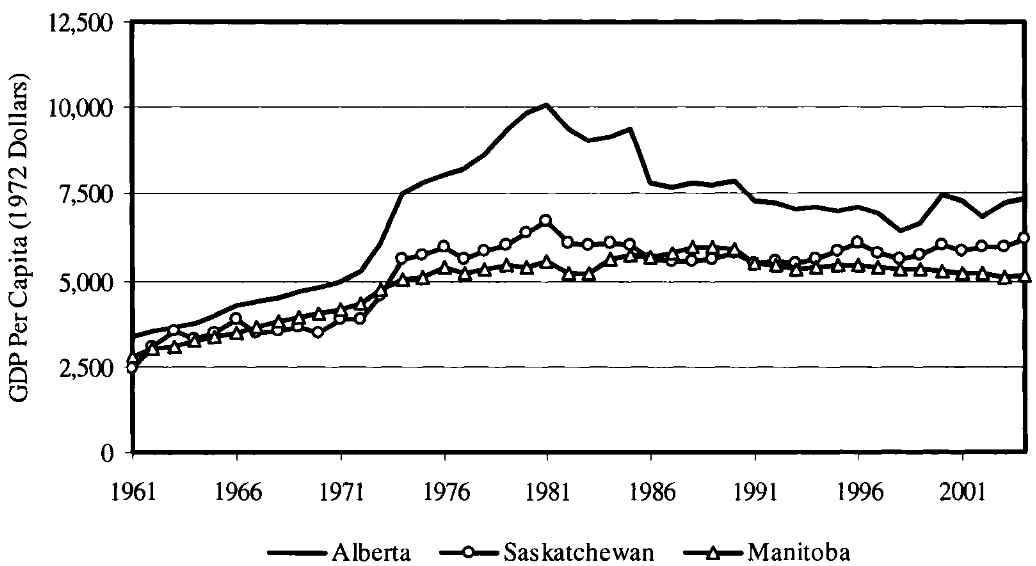
The final explanation for the recorded productivity growth that is evaluated focuses on the distinct economic conditions facing agriculture in the Prairie provinces. It has been noted that Alberta is the least productive province in terms of both livestock and crops over the 1940 to 2004 period. Any explanation that endeavours to explain this fact would be remiss if it did not account for, arguably, the most substantial overall economic difference between the three Prairie provinces, Alberta's extensive economic growth related to its oil and gas resources.[19] Figures 7.11, 7.12 and 7.13 quantify, in a

[19] Jim Unterschultz (Associate Professor, Department of Rural Economy) initially suggested that Alberta's oil and gas development could play an important role in explaining the province's lagging agricultural productivity growth.

rudimentary manner, the considerable importance of oil and gas to the overall provincial economy.

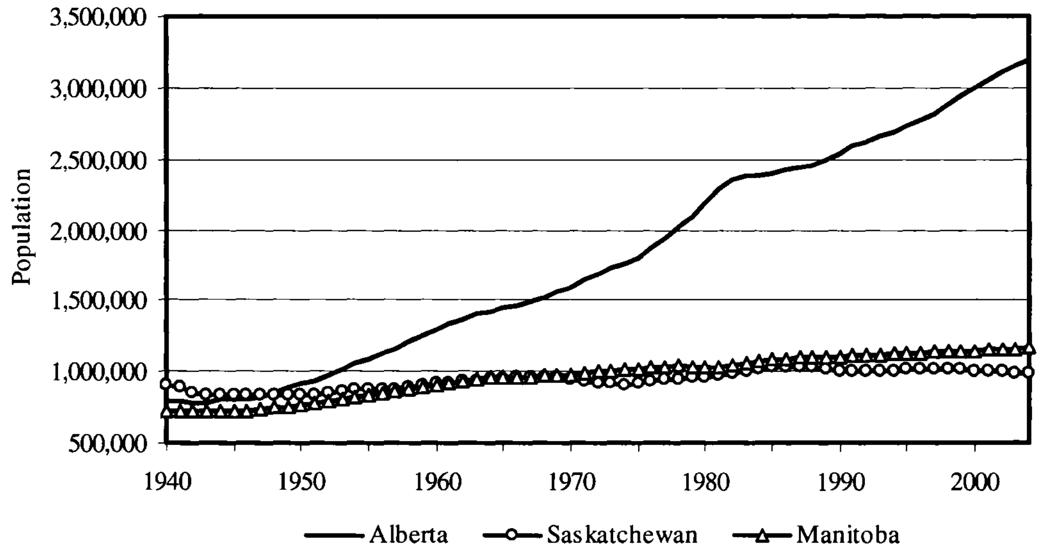
Figure 7.11 shows the dramatic increase in real per capita income in Alberta from the early 1970's through to 1981. The rapid increase in real per capita income is even more remarkable considering that Alberta's population grew 35 percent from 1972 to 1981 (see Figure 7.12). The increase in per capita income is largely attributable to the booming provincial oil and gas sector during this period. The considerable growth in Alberta's population from 1940 to 2004 also differentiates the province from both Saskatchewan and Manitoba, and is due in large part to the in-migration engendered by Alberta's oil and gas activity from the 1950's onward (Applied History Research Group, 1997).

Figure 7.11 Per Capita Provincial GDP (1972 Dollars): Alberta, Saskatchewan, and Manitoba, 1961-2004[20]



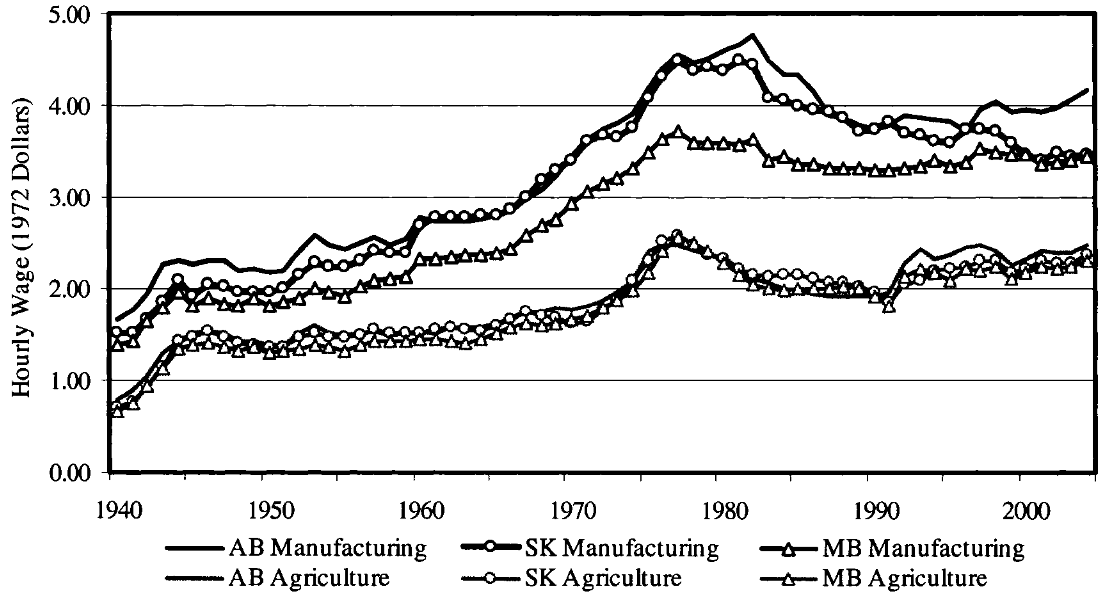
[20] Provincial GDP data are not readily available from Statistics Canada prior to 1961.

Figure 7.12 Population: Alberta, Saskatchewan, and Manitoba, 1940-2004



Alberta's oil and gas development is hypothesized to have a number of important impacts on the province's agricultural sector. First, resources are reallocated from agriculture towards the more prosperous oil and gas sector. Figure 7.10, for instance, indicates a higher off-farm labour rate in Alberta than in Saskatchewan and Manitoba. If the oil and gas activities are drawing away the most productive agricultural labour then this will have detrimental effects on agricultural productivity. Figure 7.13, graphs the real hourly wages for manufacturing (a proxy for unskilled and semi-skilled oil patch employment) and hired agricultural labour, and shows that Alberta's real manufacturing wage is the highest among Prairie provinces. This finding suggests that it may be more difficult for Alberta producers to hire labour; and perhaps more importantly that Alberta producers face a higher opportunity cost for their own labour. Interestingly, Saskatchewan also has relatively high manufacturing wages for many periods, perhaps as a consequence of its low labour supply (i.e. low and negative population growth during some periods). Manitoba agriculture, in contrast, may be able to benefit from its relatively low wage rates.

Figure 7.13 Hourly Wage Rates for Manufacturing and Agriculture (1972 Dollars): Alberta, Saskatchewan, and Manitoba, 1940-2004



Second, land prices have risen very rapidly in Alberta, relative to Saskatchewan and Manitoba (see the land price indexes in Tables B.1 through B.6) this is to a large extent the result of oil and gas generated economic growth. The pressures on two of the key inputs to agricultural production (i.e. land and labour) may not permit the most productive mix of inputs or the use of the highest quality inputs (e.g. high quality labour and productive land surrounding growing urban centers).

The importance of energy development in Alberta may also result in a greater number of farms where operators farm intermittently, working off farm much of the year, and farming as much for lifestyle and/or tax purposes as for agricultural production. In this context, the incentives for these producers to adopt increasingly productive technologies and management strategies may be low, relative to Saskatchewan and Manitoba producers. The nature of the off farm work may also serve to negatively effect the timing of on-farm agricultural operations in Alberta.

The complete impact of the oil and gas development on Alberta agriculture is complex. For example, it can be argued that oil and gas development in Alberta has led to superior provincial infrastructure, particularly in regard to the transportation network;

this would undoubtedly advance agricultural productivity. However, a detailed exploration of the impact of oil and gas development on the agricultural sector is beyond the scope of this study. It is hypothesized that the net impact of Alberta's oil and gas development and the pressures it imposes on key agricultural inputs is to retard agricultural productivity growth in the province. In this context, Alberta's oil and gas endowment is viewed from the "natural resources curse" paradigm.[21]

7.3 Econometric Evaluation of Causes of Prairie Agricultural Productivity Growth

In Section 7.2 eight categories of causal explanations for measured productivity growth in Prairie agriculture were evaluated. In some cases, the explanations' impact on productivity growth is ambiguous. Nonetheless, reviewing the factors likely responsible for agricultural productivity growth accomplishes two objectives: first, it points to reasonable explanations that are not amenable to quantification, yet are an important part of the explanation for Prairie productivity growth; second, it points to causal explanations that can be quantified and modeled econometrically. The objective of this section is to model, to the extent possible, the eight explanations for the productivity growth, using in most cases data presented graphically in Section 7.2.

7.3.1 Econometric Modeling

The econometric modeling in this section largely follows the approach of Huffman and Evenson (1993).[22] A complete list and description of the dependent and independent variables is presented in Table 7.2. A three equation SUR model is estimated with aggregate TFP (*ATFP*), crops TFP (*CTFP*), and livestock TFP (*LTFP*) indexes for the Prairie provinces as the dependent variables and a common set of explanatory variables across the equations. Although somewhat ad hoc in nature, the system of equations (7.1, 7.2 and 7.3) is empirically tractable and permits an assessment

---

[21] Sachs and Warner (2001) present greater detail and empirical evidence regarding the "natural resources curse". Although they analyze nation states, many of their findings point to issues that are likely present to some degree in hydrocarbon rich Alberta.

[22] In some cases the variables used in this analysis are different from those used by Huffman and Evenson. This is a reflection of data differences, and explanations for productivity growth with specific relevance to Prairie agriculture.

of the statistically and economically significant factors underpinning productivity growth in crops and livestock for the Prairie provinces.

Aggregate Agriculture Equation:

$$
(7.1) \quad \begin{aligned} &\ln ATFP = B_{11} + B_{22} S_C \ln CRD + B_{23} S_C \ln IOP + B_{24} S_C \ln FSZ + B_{25} S_C \ln SPL + B_{26} S_C \ln TOT \\ &B_{32} S_L \ln CRD + B_{33} S_L \ln IOP + B_{34} S_L \ln FSZ + B_{35} S_L \ln SPL + B_{36} S_L \ln TOT \\ &B_{17} \ln SCH + B_{18} \ln EXT + B_{19} \ln SUP + B_{110} \ln OFF + B_{111} \ln WRT + B_{112} T^2 \end{aligned}
$$

Crops Agriculture Equation:

$$
(7.2) \quad \begin{aligned} &\ln CTFP = B_{21} + B_{22} \ln CRD + B_{23} \ln IOP + B_{24} \ln FSZ + B_{25} \ln SPL + B_{26} \ln TOT \\ &B_{27} \ln SCH + B_{28} \ln EXT + B_{29} \ln SUP + B_{210} \ln OFF + B_{211} \ln WRT + B_{212} T^2 \end{aligned}
$$

Livestock Agriculture Equation:

$$
(7.3) \quad \begin{aligned} &\ln LTFP = B_{31} + B_{32} \ln CRD + B_{33} \ln IOP + B_{34} \ln FSZ + B_{35} \ln SPL + B_{36} \ln TOT \\ &B_{37} \ln SCH + B_{38} \ln EXT + B_{39} \ln SUP + B_{310} \ln OFF + B_{311} \ln WRT + B_{312} T^2 \end{aligned}
$$

Note: right hand side variables described in Table 7.2.

Revenue share weights are used to normalize variables that are calculated separately for crops and livestock and which appear in the aggregate equation (7.1). Coefficients for the revenue share weighted variables are restricted across equations to gain consistency in interpretation and improve the efficiency of the estimation. The model is a log-log transformation, thus the reported coefficients are measures of elasticity.[23]

---

[23] A limitation to the SUR approach is that it does not handle the potential endogeneity of some independent variables. In particular, structural change variables may be endogenous. Huffman and Evenson (2001) develop a six equation three stage least-squares model to incorporate the endogeneity of the structural change variables. Due to data limitations similar modeling is not pursued in this study.

7.3.2 Model Data

Table 7.2 lists the variables used in the econometric model. All categories of explanations presented in Table 7.1 are included in the model, with the exception of geoclimatic differences.[24]

Table 7.2 Definition of Variables: Causes of Prairie Productivity Growth and Variation, 1940-2004

Variable	Description
TFP	Respective TFP indexes. (Crops = *C*, Livestock = *L*, Aggregate = *A*).
CRD	Canadian federal, provincial, and private stock of R&D expenditures in 1972 dollars. 20 year lag structure (7 rising + 6 constant + 7 declining). (Crops, Livestock)
SCH	Index of average years schooling completed.
EXT	Provincial extension expenditures in 1972 dollars. 3 year lag (.5, .25, .25)
IOP	Inherent output productivity differences. Canola and specialty crops as a share of total crops output. Swine as a share of total livestock output. (Crops, Livestock)
SUP	Direct program payments to producers in 1972 dollars.
FSZ	Farm size index, based on value of output. (Crops, Livestock)
SPL	Crop and livestock specialization. Share of cropped land in specialized crops farms and share of livestock in specialized livestock farms. (Crops, Livestock)
OFF	Share of operators reporting off-farm labour.
TOT	Terms of trade index. (Crops, Livestock)
WRT	Ratio of hourly manufacturing to hired farm labour wage.
T	Time trend. Using first differenced data the constant is interpreted as the linear time trend.
T^2	Quadratic time trend.

[24] Compiling accurate provincial level indexes of geoclimatic differences is an empirically intensive task, and is beyond the scope of this study. See Veeman and Fantino (1985) for an effective approach to modeling weather indexes.

The derivation of the variables is analogous to what was presented (and graphed) in Section 7.2, with two exceptions. First, there is the manufacturing to farm wage ratio (*WRT*) for which the derivation is self-evident. Second, inherent output productivity (*IOP*) is a measure of the share that canola and specialty crops comprise of total crop output, and the share that swine comprise in total livestock output. The hypothesis for the inherent output productivity variable is that canola and specialty crops, and swine are inherently productive outputs relative to other crop and livestock outputs.

All indexes are normalized at 1972. The data are pooled for the three Prairie provinces. To remove the fixed effect (the unobserved affect of each province) the data are first differenced (Wooldridge, 2003).

7.3.3 Empirical Results

Table 7.3 reports the coefficient estimates for the iterated SUR.[25] A number of key coefficients (e.g. R&D and terms of trade) are statistically significant, especially in the case of the livestock sector. However, many of the other coefficients are not statistically significant. This is a reflection of a number of factors: first, the model is somewhat ad hoc in design and the lack of statistical significance may reflect this; second, although pooling the provinces increases the sample size (n = 192) the degrees of freedom are still limited; third, a number of different time lags and transformations have been tried with the independent variables, but there may be room for further refinements.

Nonetheless, the reported coefficients do indicate a number of interesting findings. The most striking finding in terms of statistical and economic significance is that importance of the stock of Canadian R&D expenditures (ln*CRD*) to crops and livestock productivity. The coefficients for livestock and crops indicate that the stock of Canadian R&D investments plays the preeminent role in generating productivity growth.

Another factor that plays a decisive role is the terms of trade (ln*TOT*). The negative relationship between terms of trade and productivity indicates that crops and livestock producers become more productive in response to declining (negative) terms of trade. This finding suggests that producers are able to respond effectively to cost price pressures by successfully adopting innovation. The impact is larger in crops and

---

[25] Additional econometric testing and results are reported in Appendix E.

represents a more successful response by the crops farmers to their more rapidly deteriorating terms of trade.

In terms of structural change, most of the relationships are statistically insignificant (i.e. specialization, and off-farm labour). However, farm size (ln*FSZ*) appears to play an important role in generating productivity advance in livestock. It was determined in Section 6.2 that livestock enjoys considerable economies of scale at the aggregate level. The results presented in Table 7.3 indicate that substantive economies of scale also exist at the firm level.

Section 7.3 presented the argument that certain output types may be inherently more productive than others. This argument is substantiated in the case swine (ln*IOP*); all else being equal, a larger share of swine in a province's livestock output increases productivity. The same is not true for canola and specialty crops. Although statistically significant the coefficient is economically insignificant (i.e. close to zero in magnitude). Relatively new crop varieties do not appear to be inherently any more productive than the traditional crops (e.g. wheat or barley).

The final coefficients that exhibit statistical significance are the two time trends for livestock (T and T^2). The negative coefficient on the simple time trend is likely an indication of the tendency for productivity to regress in the absence of other factors promoting productivity growth. The trend towards productivity regress over time is most likely due to animal diseases (see Townsend and Thirtle (2001) for a further discussion in the context of developing nation agriculture). The positive coefficient on the squared time trend is more difficult to explain, and is probably serving as a proxy for omitted variables (e.g. the growing importance of infrastructure over time).

Table 7.3 Coefficient Estimates, Causes of Productivity Growth SUR Model: Three Province Pooled Data, 1940-2004

Variable	Description	Crops Equation (7.2)	Livestock Equation (7.3)	Aggregate Equation (7.1)
ln*CRD*	Canadian R&D expenditure stock	0.5650**	0.6133**	As in crops and livestock
ln*SCH*	Years of operator schooling	0.2578	0.5047	0.3650
ln*EXT*	Provincial extension expenditures	-0.1800	-0.0731	-0.1534
ln*IOP*	Inherent productivity differences between outputs	-0.0291*	0.1044**	As in crops and livestock
ln*SUP*	Direct program payments to producers	0.0106	0.0066	0.0086
ln*FSZ*	Farm size as measured by output	0.0235	0.3819**	As in crops and livestock
ln*SPL*	Farm specialization in producing crops or livestock	-0.3653	-0.0410	As in crops and livestock
ln*OFF*	Operators reporting off-farm labour	-0.1610	-0.0722	-0.1371
ln*TOT*	Terms of trade	-0.3366**	-0.1813**	As in crops and livestock
ln*WRT*	Ratio of manufacturing to hired farm labour wages	0.3544	0.0541	0.2598
T	Time trend	-0.0261	-0.0607**	-0.0352
T^2	Quadratic time trend	0.2705	0.0005**	0.0003

** and * denote statistical significance at the one and five percent level of significance respectively

7.4 Analysis of the Causes of Prairie Agricultural Productivity Growth

After evaluating various qualitative and quantitative explanations for productivity growth it is clear that no one factor can adequately account for the measured variation in productivity growth rates. This is not a surprising finding. The story behind Prairie agricultural productivity growth is complex; likely all the individual factors examined play a role in productivity growth and interact with each other in a complex chain of causation. The eight categories of explanations are briefly reviewed prior to offering conclusions and policy implications in Chapter 8.

7.4.1 Research and Development

From both a qualitative and quantitative standpoint, stocks of R&D expenditures play a fundamental role in generating productivity growth. It was not possible to model R&D spill-ins from Eastern Canada and from the United States. However, it is anticipated that these additional sources of R&D would generate substantial productivity growth in crops and particularly in livestock where R&D investments are less geoclimatically sensitive.

7.4.2 Education and Extension

Empirically, neither operator education or provincial extension expenditures are statistically significant. Nonetheless, over the sixty-five year period of the study, crops and livestock farming in the Prairies has become an increasingly technical vocation requiring well developed analytical and managerial skills. It is difficult to support a hypothesis which does not recognize the vital contribution of farmer education and extension to the adoption of novel technologies in their broadest sense, and related productivity growth.

7.4.3 Terms of Trade

The terms of trade are statistically significant and have a relatively large economic impact for both crops and livestock productivity growth. The implication is that producers respond to the cost price squeeze by adopting productivity enhancing technologies. It is also apparent that over time crops farming has exhibited a stronger response to its declining terms of trade. This finding suggests that crops farming faces more intense treadmill pressures than livestock farming.

7.4.4 Inherent Biological and Production Process Related Productivity Differences

The regression results indicate that swine can be viewed as an inherently productive livestock output. Canola and specialty crops do not appear to share this same attribute. It is also likely that crops can be viewed, in general, as inherently productive relative to livestock following Huffman and Evenson's (1993) rationale. However, crops' inherent productivity relative to livestock may be eroding as the Prairie livestock sector increasingly adopts or has adopted controlled genetics and controlled industrial type intensive livestock operations for swine, poultry, dairy, and to a lesser extent cattle.

7.4.5 Geoclimatic Differences

Geoclimatic differences are difficult to model effectively and thus were not included in the empirical analysis. There can be as much variation in soils and climate inside in a province as there is between provinces. Compiling a representative index of geoclimatic conditions for each Prairie province was beyond the scope of this work. Although geoclimatic differences have not been modeled formally, it is difficult to overstate the importance of geoclimatic conditions to agriculture, and its productivity growth.

7.4.6 Government Policy

Government policy is only modeled to the extent that it is represented by direct program payments to producers. The government policy variable is statistically insignificant. Of course, government agricultural policy is far more involved than simply direct payments to producers. The free trade agreements and the removal of the Crow rate have likely played important roles in generating productivity growth in Prairie livestock; and supply management is certainly expected to influence productivity growth, yet its impact is ambiguous.

7.4.7 Structural Change

Average farm size is statistically significant for livestock, indicating that economies of scale at the firm level are a vital component of livestock productivity growth. Farm size for crops is statistically insignificant. This may suggest that after a certain size additional expansion in crops farm size does not generate productivity growth. The other structural change variables (off-farm labour and specialization) are not statistically significant. The impact that increased off-farm labour has on productivity growth is not clear, so the model's findings are plausible. However, intuitively it is likely that crops and livestock specialization would have a positive impact on productivity growth for both livestock and crops.

7.4.8 Regional Economic Conditions

Due to data and time constraints regional economic conditions were not explicitly modeled. Variables for off-farm labour participation and the ratio of manufacturing to hired farm labour wages serve implicitly to model some elements of the regional economic conditions. Yet neither variable is statistically significant. In many respects regional economic conditions are the social science equivalent of geoclimatic conditions. Compiling an index that can effectively represent the economic condition of a province or even a region is not a trivial exercise. Although difficult to model, regional economic conditions impinge on the economic decisions of producers. In particular, it is probable that the economic decisions of producers in Alberta are greatly impacted by the economic realities of Alberta's vast conventional and unconventional oil and gas deposits and related development. Any account of Alberta agricultural productivity growth should include the unique economic circumstances (and perhaps the "natural resource curse") of this Prairie province.

CHAPTER 8: CONCLUSIONS AND POLICY IMPLICATIONS

8.1 Review of Productivity Growth Rates

Table 8.1 is a summary table of the average annual compound agricultural productivity growth rates presented in Chapter 5. The results presented in Table 8.1 form the basis for the conclusions and discussion that takes place throughout Chapter 8. From Table 8.1 the broad trends in agricultural productivity growth in the Prairies, and its component provinces, can be discerned. The key trends in the productivity growth rates depicted in Table 8.1 inform the four stylized questions presented in the following section.

Table 8.1 Prairie, Alberta, Saskatchewan and Manitoba Crop and Livestock TFP Annual Growth Rates

		1940-2004 %	1940-1959 %	1960-1979 %	1980-2004 %	1994-2004 %
Crops	Prairies	1.77	1.55	1.89	1.77	0.59
	Alberta	1.65	1.36	1.62	1.04	-0.33
	Saskatchewan	1.76	1.97	2.00	2.11	0.39
	Manitoba	2.12	0.90	2.67	2.47	2.70
Livestock	Prairies	0.65	-0.02	0.33	1.12	2.49
	Alberta	0.54	0.24	0.19	0.34	0.58
	Saskatchewan	0.59	-0.39	0.19	1.86	4.28
	Manitoba	0.97	0.04	0.78	2.13	5.33

8.2 The Causes of Prairie Agricultural Productivity Growth

Much of the analysis in this study focuses on the differences in productivity growth rates between livestock and crops, over time, and among provinces. Prior to focusing again on the variations in productivity growth rates it is worth noting that considerable productivity growth has occurred in Prairie agriculture over the sixty-five years of the study.[1]

At the end of Chapter 5 four stylized questions concerning productivity growth in Prairie agriculture were posed. In Chapter 6 these questions were answered on the basis of Chapter 6's findings of scale effects and technical change in crops and livestock farming in the three Prairie provinces. By posing these four questions again and using the causal analysis presented in Chapter 7, the answers can be further refined and extended.

1. *What accounts for the lower productivity growth rates in livestock farming relative to crops?*

   Technical change has been more rapid in crops. To a certain extent this is apt to be the result of greater R&D expenditures over time in crops relative to livestock. However, inherent productivity differences between livestock and crops likely play a more critical role. The productivity differences inherent in the biology and production processes of crops farming may have permitted greater opportunity for the adoption of technological innovations over the past sixty-five years.

   Crops farming has also faced greater cost price pressures than livestock (i.e. its terms of trade have been worse). Since crops farming is able to leverage superior productivity growth in response to declining terms of trade this has permitted greater productivity growth, relative to livestock.

2. *Why has livestock productivity growth accelerated considerably over the past twenty-five years in Saskatchewan and Manitoba, while only moderately in Alberta?*

---

[1] From 1940 to 2004 output growth has increased at average annual compound growth rates of 2.68 and 1.56 percent per annum for Prairie crops and livestock, respectively. Of this output growth, 66 and 42 percent is the result of productivity growth, an impressive record.

Two factors are largely responsible for Manitoba's rapid livestock productivity growth over the past twenty-five years. First, Manitoba's swine sector has expanded considerably. As an inherently more productive livestock output (relative to cattle), swine has pushed productivity growth rates upwards in Manitoba. Second, the average livestock farm size has increased more rapidly in Manitoba than in Saskatchewan or Alberta over this period. Manitoba has been more effective in realizing productivity growth from both aggregate and firm level economies of scale than either Saskatchewan or Alberta.

It is more difficult to explain why productivity growth in Saskatchewan livestock outpaces Alberta livestock over the past twenty-five years. In both provinces, livestock output composition is dominated by cattle production. A key difference however is the role the two provinces play in the beef supply chain. Saskatchewan cattle production is concentrated at the cow-calf level with substantial cattle exports to Alberta for finishing where large scale feedlots and slaughter facilities exist. From this standpoint, however, it would be expected, intuitively, that livestock productivity growth would be higher in Alberta due to its large scale operations. The causes of the livestock productivity differences existing between Saskatchewan and Alberta remain an open question. What is clear is that, for whatever reason, Saskatchewan has benefited from markedly higher rates of technical change in livestock. Alberta's distinct economic conditions (i.e. the possible adverse consequences of its oil and gas development – the "natural resources curse") may offer a partial explanation for the divergence.

3. *Why has crops productivity growth slowed in Alberta and Saskatchewan from 1994 to 2004, and increased in Manitoba over the same period?*

The decline in Alberta and Saskatchewan's crops productivity growth may be attributed in part to the leveling off of the crops stock of R&D from 1990 onward. In contrast, productivity growth in Manitoba crops maintains a relatively strong rate of growth from 1994 to 2004. Relative to Alberta and Saskatchewan, Manitoba is geoclimatically better suited for crops production. It has more fertile soils, more heat units, and is typically not as sensitive to drought. Superior geoclimatic conditions can affect agricultural productivity directly and also indirectly through the more effective adoption of technologies. For instance, Manitoba's superior growing conditions permit a broader range of crop options (more genetic choice), and land management strategies. This can account for the higher rate of technical change in Manitoba crops in comparison with Alberta and Saskatchewan, hence its greater crops productivity growth.

4. *Why are both crops and livestock productivity growth rates somewhat higher in Saskatchewan than in Alberta, and considerably higher in Manitoba?*

   Manitoba's agricultural productivity growth benefits from the province's superior geoclimatic conditions. In addition, over the past twenty years in crops and past ten years in livestock, the average farm size in Manitoba has grown rapidly, relative to the other two Prairie provinces. The firm level economies of scale realized through increased farm size have contributed to Manitoba's elevated agricultural productivity growth. As well, Manitoba's specialization in swine production has improved its productivity growth in the livestock sector, relative to Alberta and Saskatchewan.

   Saskatchewan's agricultural productivity growth is somewhat higher than Alberta's; however, it is not as high as Manitoba's productivity growth. Due to the similarities between Saskatchewan and Alberta, geoclimatically, and in terms of output composition, the cause of the divergent productivity growth between the provinces is not obvious. However, it is again probable that the different provincial economic conditions may explain a substantive portion of the difference.

The four stylized questions reviewed focus on the differences in the productivity growth rates between livestock and crops, over time, and among provinces. However, many of the causal explanations presented in Chapter 7 may contribute to a basic common level of agricultural productivity growth over time rather than accounting for sectoral, intertemporal, or provincial variations in growth. For instance, R&D

expenditures, farmer education and extension may be responsible for maintaining a basic level of agricultural productivity growth over time.

8.3 Policy Implications

The findings of this study have a number of implications for public policy. It is recognized that productivity growth is only one of a multiplicity of issues to which effective agricultural policy must respond. Nonetheless, productivity growth is critically important to agriculture in terms of its long run economic sustainability and thus should be a matter for serious consideration when developing agricultural policy. Section 8.2 summarizes four noteworthy policy implications from the study.

8.3.1 Research and Development

From both a qualitative and quantitative perspective the stock of domestic R&D expenditures plays an essential role in generating agricultural productivity growth. The leveling off in the stock of R&D expenditures may therefore be an important long term concern. The crops R&D stock levels off in the early 1990's, while the livestock R&D stock levels off by the late 1980's. It is hypothesized that a growing stock of R&D investments provides a long term basic level of productivity growth. If the stock of R&D investments is constant, however, it will generate only a maintenance level of productivity – that is, no productivity regress, but yet no productivity growth. In this sense a constant R&D stock is not a driver of productivity growth; it is solely a backstop to productivity decline resulting from deteriorating agricultural conditions (e.g. crop and animal disease or deteriorating land productivity).[2]

The federal government funds the majority of Canadian agricultural R&D, while the provinces and private sector account for smaller shares. To ensure a baseline level of agricultural productivity growth, long term agricultural R&D expenditures may need to increase. If increased funding by the federal government is required, then a reciprocal commitment by the provinces will also likely be needed to increase the stock of domestic

---

[2] Productivity growth will still occur with a leveling off of the R&D stock, but the productivity growth will be due to other causal factors; this is not an effective strategy in pursuing long run stable productivity advance in agriculture.

R&D. Due to the public good nature of much agricultural research, it is not clear that private sector R&D expenditures in the short run can bridge a potential gap left by constant public funding of R&D. Foreign R&D may spill-in from the U.S., but to the extent that the R&D is geoclimatically sensitive it may have limited impacts on productivity growth (livestock may fare better than crops in regard to R&D spill-ins).

A further issue in relation to agricultural R&D is the declining real levels of public provincial extension expenditures. Given the importance of extension in helping producers adopt novel technologies and management strategies it is not clear that an increase in R&D expenditures alone without concurrent expansion in extension programs would achieve the desirable advances in productivity. However, extension activities are being increasingly performed in the private sector, and it is certainly possible that total real extension expenditures have not dropped off. Rather, they have been reallocated between the private and public sector.

A determination of the most productive mix of R&D funding with respect to basic and applied science, and crops and livestock is beyond the scope of this study. However, there may be some specific outputs where Prairie (and Canadian) agriculture have a comparative advantage and R&D efforts would be best concentrated.

8.3.2 Livestock Productivity and Aggregate Economies of Scale

Much of the productivity growth in Prairie livestock over the past twenty-five years is attributable to aggregate economies of scale. The considerable increases in livestock output over this period, principally cattle in Alberta and Saskatchewan and swine in Manitoba, have generated substantial productivity growth in Prairie livestock production. The productivity growth in and of itself is positive; however, concerns remain regarding future productivity growth. If past trends are persistent, then the majority of future productivity growth will be generated by aggregate economies of scale. Unlike productivity improvements obtained via technical change, this will require increased output expansion. Yet there are limits to further livestock output expansion. Firstly, the swine and cattle sectors rely to a great extent on export markets and are very sensitive to international trade restrictions.[3] Second, it is not clear that the environmental costs of continued long term increases in swine and cattle production will be politically and/or scientifically saleable.

This may be an overly pessimistic view. Livestock production has recorded slow rates of technical change in the past, but given the rapidly changing production practices, swine and cattle production may be able to adopt technologies at an increasing rate in the future. Of course, technical change does not happen in a vacuum and this view supports the argument for increased livestock R&D expenditures.

8.3.4 Structural Change

The only statistically significant measure of structural change on productivity growth in this study is average farm size for livestock. The results of this study, and casual empiricism, suggest that increasing livestock farm size is a reality, and the increased industrialization of this sector, particularly in regard to swine production, is leading to considerable productivity growth.

In addition, it is anticipated that other measures of structural change have substantive positive impacts on productivity growth, since structural change is being pursued by producers because of its economic benefits. Thus policies that explicitly or implicitly retard structural change will, in addition, hinder productivity growth. There may be sensible reasons for pursuing policy that impedes structural change (e.g. policies designed to preserve the "family farm" or encourage the development of smaller farms producing niche specialty products). However, there should be a recognition that a tradeoff is made in terms of slower productivity growth.

8.3.5 Productivity Growth and Specific Agricultural Outputs

From 1940 to 2004 agricultural outputs have changed considerably in crops and livestock (see Section 4.2). In some cases, changing agricultural outputs leads to productivity growth advantages (e.g. the expansion of swine production in Manitoba). In

[3] The finding of BSE in an Alberta cow (May 2003) resulted in extensive international trade restrictions with profound financial implications for the Canadian cattle industry. It is impossible to predict with certainty when the next crisis will arise, but to the extent that livestock producers depend on external trade they are placed at greater risk.

other cases, changes in outputs offer minimal evidence of productivity growth (for example, although beneficial in terms of cash receipts, canola does not appear to have been any more productive over time than the more traditional crops such as wheat or barley). From a policy perspective it is important to be able to assess the productivity growth of individual commodities. This knowledge can help in the design of research programs that can promote productivity growth in outputs where it has previously been limited, with the long run goal of diversifying agricultural production. Conversely, research could be focused on specific groups of inherently highly productivity commodities to promote comparative advantage in Prairie and Canadian agriculture. In either case, the composition of Prairie agricultural output has altered considerably and responding to future changes will be a challenge for publicly funded agricultural research.

8.4 Study Limitations and Further Research

This study has undertaken a comprehensive analysis of Prairie agricultural productivity growth at the aggregate level. Nonetheless, any study has limitations and can be further refined with additional data and time. The following comments are a summary of the study's limitations, and directions for further research. Through further work some of the conclusions which at this stage are essentially informed hypotheses may be rendered more rigourous in character. In turn, it will be possible to derive further policy implications from this expanded work.

8.4.1 Expanding Productivity Growth Estimates

The measurement of agricultural productivity growth is a key focus of this study and underpins the ancillary causal analysis. Using a similar productivity growth methodology it is desirable to expand the analysis to British Columbia, Ontario, Quebec and the Maritimes. The productivity growth results for the additional provinces are of interest on their own merits. As well, the expanded data would permit a more effective assessment of the causes of productivity growth and their variation between provinces and different outputs. Econometrically the expanded cross-sectional time series would permit more sophisticated modeling of the causal explanations for productivity growth.

Another direction in which the productivity growth rate measures can be taken is in determining output specific productivity growth rates. Results from this work would prove useful in targeting research expenditures and/or assessing the productivity payoffs from output specific R&D investments. Many of the methodological challenges of allocating inputs between crops and livestock would be present when constructing total factor productivity measures for individual outputs.

The Prairie agricultural productivity growth estimates can also be adjusted to account for factor bias or even environmental impacts. Correcting the TFP measures for factor bias is principally an econometric exercise (Bailey, 2004), and is relatively straightforward. Adjusting TFP for environmental impacts, although of great interest, is conceptually challenging, and empirically difficult due to the limited data regarding environmental impacts (when they occur). Nonetheless, effective methodologies have been advanced that can integrate environmental goods and bads into productivity analysis (for two potential approaches see Färe and Grosskopf (1998), and Weaver (1998)).

8.4.2 Further Modeling of the Causal Explanations

With more detailed data and further econometric modeling the role of the specific causal explanations in measured agricultural productivity growth can be refined. From a data perspective, more detailed R&D data are desirable. Specifically, the relevant R&D spill-ins from Eastern Canada and the United States should be integrated into the model. In addition, representative indexes of the geoclimatic and economic conditions for each province should be added.

From an econometric standpoint, potential endogenity in the independent variables has not been addressed. Huffman and Evenson (2001) use a three-stage least squares system of equations to deal with potential endogeneity (i.e. common factors correlated with both the productivity and structural change variables) in the structural change variables. Extending the productivity growth measures to the remaining provinces will permit more sophisticated modeling methodologies including three-stage least squares. The expanded cross-section of provinces would also permit added flexibility in testing a number of alternate lag structures for the independent variables.

8.4.3 Government Policy

The role of government policy in Canadian agriculture is considerable. Although a proxy for government policy is presented in the modeling of causal explanations by using direct payments to producers, further work is required. In terms of causal explanations, a number government policies should be included in the causal analysis in order to assess their impact on productivity. The two most significant policies that should be addressed, in relation to agricultural productivity, are the removal of the Crow rate and the implementation of the FTA and NAFTA. It is likely that both policies served to increase productivity growth in livestock relative to crops.

A second issue is the degree to which the TFP measures account for indirect government support. The index number approach to TFP measurement assumes perfect competition. Supply managed industries (i.e. dairy and poultry) do not approximate the competitive ideal. By restricting output, supply management results in prices above the market equilibrium price. If supply management increases the livestock revenue share of dairy and poultry, then the measured productivity growth is disproportionately influenced by the supply managed industries. The opposite is true if supply management decreases the livestock revenue share of dairy and poultry. The ultimate impact on the productivity growth estimates will also depend on whether dairy and poultry are more or less productive than the other livestock outputs. Nonetheless, the impact of supply management on the TFP estimates is mitigated by the relatively small share that dairy and poultry comprise in total livestock output in the Prairies.

8.4.4 Aggregate and Firm Level of Analysis

This study takes place at the aggregate level and covers the broad trends in Prairie agriculture and its component provinces from 1940 to 2004. The aggregate methodology permits an evaluation of macro level trends in Prairie agriculture. However, this approach is also limited in terms of farm level analysis. Future work that integrates micro level farm level analysis with the macro conclusions of this study would be ideal. Conclusions from one approach would offer insight into the findings of the other. From the aggregate perspective, micro level analysis would make the causal explanations and policy implications drawn from them more robust. At the firm level, individual producers could be situated in the context of broad sectoral trends and the external influences on their production decisions.

8.5 Conclusion

The focus of this study has been an analysis of productivity growth in Prairie agriculture. A number of factors have been reviewed that can explain much of the agricultural productivity growth that has occurred in the Prairie crops and livestock sectors from 1940 to 2004. However, the extent to which past productivity growth is representative of future trends is an open question.

With an eye to the future, two recent agricultural productivity growth trends should be highlighted. First, productivity growth in the Alberta and Saskatchewan crops sectors has slowed from 1994 to 2004. If this trend is persistent, and crops productivity growth continues to slow throughout the twenty-first century, crops farming in the Prairies will remain a tenuous proposition. Nonetheless, productivity growth in crops has been robust over the entire 1940 to 2004 period. It may be that the recent decline in crops productivity is an aberration from historical norms and a return to stronger growth rates should be anticipated. In contrast, productivity growth in the livestock sector has advanced relatively rapidly from 1980 to 2004. This finding suggests the continuation of livestock as the more profitable sector in Prairie agriculture. However, much of the productivity growth in the livestock sector is associated with rapid output expansion, which, given the uncertainty of export markets (for example, regarding BSE in cattle), is cause for concern. From a policy standpoint, assessing the persistence of these two trends is critical to the development of effective long term farm policy, especially in light of the chronic farm income problem in Prairie and Canadian agriculture, and the challenges posed by rising energy prices and the appreciation of the Canadian dollar.

BIBLIOGRAPHY

Abramovitz, M. "Resource and Output Trends in the United States Since 1870." *American Economic Review* 46(1956):5-23.

Adamowicz, W. "Production Technology in Canadian Agriculture." *Canadian Journal of Agricultural Economics* 34(1986):87-103.

Alberta Agricultural Research Institute. Annual Report. Various Years. Edmonton, Canada.

Alberta Agricultural Research Trust. Annual Report. Various Years. Edmonton, Canada.

Alberta Agriculture, Food and Rural Development. Agriculture Statistics Yearbook. Various Years. Edmonton, Canada.

Alberta Agriculture, Food and Rural Development. Annual Report. Various Years. Edmonton, Canada.

Alberta Department of Agriculture. A Historical Series of Agricultural Statistics for Alberta. 1969. Edmonton, Canada.

Alston, J. and P. Pardey. "Attribution and Other Problems in Assessing the Returns to Agricultral R&D." *Agricultural Economics* 25 (2001):141-152.

Antle, J.M. and S.M. Capalbo. An Introduction to Recent Developments in Production Theory and Productivity Measurement. In: *Agricultural Productivity: Measurement and Explanation.* Edited by Capalbo, S.M. and J.M. Antle. Washington, D.C.: Resources for the Future, 1988, p.17-95.

Applied History Research Group. Post-Leduc Oil and Gas Exploration and Development. Website: http://www.ucalgary.ca/applied_history/tutor/calgary/leduc.html, Accessed: May, 2006

Bailey, A., X. Irz, and K. Balcombe. "Measuring Productivity Growth When Technological Change is Biased - a New Index and an Application to UK Agriculture." *Agricultural Economics* 31(2004):285-295.

Bailey, E.E. and A.F. Friedlaender. "Market Structure and Multiproduct Industries." *Journal of Economic Literature* 20(1982):1024-1048.

Ball, E.V. "Output, Input, and Productivity Measurement in U.S. Agriculture, 1948-79." *American Journal of Agricultural Economics* 67(1985):475-486.

Binswanger, H.P. "A Cost Function Approach to the Measurement of Elasticities of Factor Demand and Elasticities of Substitution." *American Journal of Agricultural Economics* 56(1974):377-386.

Brinkman, G. L. An Analysis of Sources of Multifactor Productivity Growth in Canadian Agriculture, 1961 to 1980, with Projections to 2000. 1984. Ottawa, Canada, Agriculture Canada.

Brinkman, G. L. and Prentice, B. E. Multifactor Productivity in Canadian Agriculture: An Analysis of Methodology and Performance 1961-1980. 1983. Ottawa, Canada, Agriculture Canada.

Canada West Foundation Special Task Force. *Western Canadian Agriculture to 1990.* Calgary, Canada: Canada West Foundation, 1980.

CanFax. Weekly Update. 1993-2004. Calgary/Guelph, Canada.

Capalbo, S.M. "Measuring the Components of Aggregate Productivity Growth in U.S. Agriculture." *Western Journal of Agricultural Economics* 13(1988):53-62.

Capalbo, S.M. and M.G.S. Denny. "Testing Long-Run Productivity Models for the Canadian and U.S. Agricultural Sectors." *American Journal of Agricultural Economics* 68(1986):615-625.

Chambers, R.G. *Applied Production Analysis: a Dual Approach.* Cambridge, U.K.: Cambridge University Press, 1988.

Christensen, L.R. "Concepts and Measurement of Agricultural Productivity." *American Journal of Agricultural Economics* 57(1975):910-915.

Cochrane, W. *Farm Prices: Myth and Reality.* Minneapolis: University of Minnesota Press , 1958.

Coelli, T., D.S.R. Rao, and G.E. Battese. *An Introduction to Efficiency and Productivity Analysis.* Norwell, Massachusetts: Kluwer Academic Publishers, 1998.

Diewert, W.E. The Economic Theory of Index Numbers: A Survey. In: *Essays in the Theory and Measurement of Consumer Behaviour.* Edited by Deaton, R. Cambridge University Press, 1981, p.163-208.

Diewert, W.E. Index Numbers. In: *The New Palgrave: A Dictionary of Economics.* Edited by Eatwell, J., M. Milgate, and P. Newman. Macmillan Press, 1987, p.767-780.

Diewert, W.E. "The Measurement of Productivity." *Bulletin of Economic Research* 44(1992):163-198.

Diewert, W.E. and A.O. Nakamura. *Essays in Index Number Theory Vol. 1.* Amsterdam, NL: North Holland, 1993.

Diewert, W.E. and A.O. Nakamura. "Index Number Concepts, Measures and Decompositions of Productivity Growth." *Journal of Productivity Analysis* 19(2003):127-159.

Fan, S. "Effects of Technological Change and Institutional Reform on Production Growth in Chinese Agriculture" *American Journal of Agricultural Economics* 73(1991):266-275.

Fantino, A.A. and T.S. Veeman. The Choice of Index Numbers in Measuring Agricultural Productivity: A Canadian Empirical Case Study. In: *Issues in Agricultural Competitiveness: Markets and Policies.* Edited by Rose, R., C. Tanner, and A.B. Margot. I.A.A.E. Occasional Paper No. 7, 1997, p.222-231.

Färe, R. and S. Grosskopf. "Shadow Pricing of Good and Bad Commodities." *American Journal of Agricultural Economics* 80(1998):584-590.

Farming For the Future Council. Annual Report. Various Years. Edmonton, Canada.

Fisher, F.M. and K. Shell. *Economic Analysis of Production Price Indexes.* Cambridge, U.K.: Cambridge University Press, 1998.

Fox, G., Brinkman, G., and Brown-Andison, N. An Economic Analysis of the Returns to the Animal Productivity Research Program of Agriculture Canada From 1968 to 1984. 1987. Guelph, Ontario, Canada, Intercambio Ltd.

Fox, G., E. Haque, and G. Brinkman. "Product Market Distortions and the Returns to Federal Laying-Hen Research in Canada: Reply and Further Results." *Candian Journal of Agricultural Economics* 38(1990):351-356.

Government of Canada. Public Accounts. Various Years. Ottawa, Canada.

Greene, W. *Econometric Analysis.* Fifth ed. Upper Saddle River, New Jersey: Prentice Hall, 2003.

Griliches, Z. "Research Costs and Social Returns: Hybrid Corn and Related Innovations." *Journal of Political Economy* 66(1958):419-431.

Griliches, Z. "The Sources of Measured Productivity Growth: United States Agriculture, 1940-1960." *Journal of Political Economy* 71(1963):331-346.

Griliches, Z. Notes on the Role of Education in Production Functions and Growth Accounting. In: *Education, Income, and Human Capital.* Edited by Hansen, W.L. New York: Columbia University Press, 1970, Griliches, Z. and F. Lichtenberg. R&D and Productivity Growth at the Industry Level: Is There Still a Relationship? In: *R&D, Patents, and Productivity.* Edited by Griliches, Z. Chicago: University of Chicago Press, 1984, p.465-96.

Griliches, Z. "Sources of Agricultural Economic Growth and Productivity: Discussion." *American Journal of Agricultural Economics* 74(1992):762-763.

Hailu, G., S. Jeffrey, and J. Unterschultz. "Cost Efficiency for Alberta and Ontario Dairy Farms: An Inter-Regional Comparison." *Canadian Journal of Agricultural Economics* 53(2005):141-160.

Hamal, K. B. Crop Productivity Analysis: Nepal, 1961-1987. 1991. Edmonton, Canada, Unpublished Ph.D. Dissertation, Department of Rural Economy, University of Alberta.

Hamilton, D. G. Evaluation of Research and Development in Agriculture and Food in Canada. 1980. Guelph, Canada, Canadian Agricultural Research Council.

Huffman, W.E. and R.E. Evenson. "Contributions of Public and Private Science and Technology to U.S. Agricultural Productivity." *American Journal of Agricultural Economics* 74(1992):751-756.

Huffman, W.E. and R.E. Evenson. *Science for Agriculture.* Ames: Iowa State University Press, 1993.

Huffman, W.E. and R.E. Evenson. "Structural and Productivity Change in US Agriculture, 1950-1982." *Agricultural Economics* 24(2001):127-147.

Huffman, W.E. and E.E. Wallace. The Effects of R&D on Farm Size, Specialization, and Productivity. In: *Industrial Policy for Agriculture in the Global Economy.* Edited by Johnson, S.R. and S.A. Martin. Ames, Iowa: Iowa State University Press, 1993.

Huot, M.F., G. Fox, and G. Brinkman. "Returns to Swine Research in Canada." *North Central Journal of Agricultural Economics* 11(1989):189-201.

Islam, T. S. Input Substitution and Productivity in Canadian Agriculture. 1982. Edmonton, Canada, Unpublished Ph.D. Dissertation, University of Alberta, Department of Economics.

Karagiannis, G. and H. Furtan. "Production Structure and Decomposition of Biased Technical Change: an Example From Canadian Agriculture." *Review of Agricultural Economics* 15(1993):21-37.

Kim, H.Y. "Economies of Scale and Economies of Scope in Multiproduct Financial Institutions: Further Evidence from Credit Unions." *Journal of Money, Credit and Banking* 18(1986):220-226.

Kohli, U. "An Implicit Törnqvist Index of Real GDP." *Journal of Productivity Analysis* 21(2004):337-353.

Manitoba Agriculture. 100 Years of Agriculture in Manitoba a Statistical Profile, 1881-1980. Winnipeg, Canada.

Manitoba Agriculture. Annual Report. Various Years. Winnipeg, Canada.

Manitoba Agriculture. Manitoba Agriculture Yearbook. Various Years. Winnipeg, Canada.

Morrison, C.J. "Unravelling the Productivity Growth Slowdown in the United States, Canada and Japan: The Effects of Subequilibrium, Scale Economies and Markups." *The Review of Economics and Statistics* 74(1992):381-393.

Mullen, J. and J. Crean. "Strong Agricultural Productivity Growth Despite Weaker Public R&D Investment: Does this make Sense?" *Farm Policy Journal* 3(2006):11-23.

Murgai, R. "The Green Revolution and the Productivity Paradox: Evidence from the Indian Punjab." *Agricultural Economics* 25(2001):199-209.

Murray, J.D. and R.W. White. "Economies of Scale and Scope in Multiproduct Financial Institutions: A Study of British Columbia Credit Unions." *The Journal of Finance* 38(1983):887-902.

Mutch, Douglas A. Livestock and Poultry Market Summary: North American and Livestock Industries. 1987. Ottawa, Livestock Feed Board of Canada.

Nasir, S. Production Structure and Changing Input Use in Prairie Agriculture. 2001. Edmonton, Canada, Unpublished M.Ag. Thesis, Department of Rural Economy, University of Alberta.

Peng, Y., Veeman, T. S., and Fantino, A. A. Assessing the Relative Roles of Technical Change and Scale Impacts in Estimated Productivity Growth in Prairie Agriculture, 1948-1994. Canadian Agricultural Economics and Farm Management Society 1997 Annual Meeting, Toronto, Canada. 97. Department of Rural Economy, University of Alberta.

Phillips, W., Bauer, L., and Akabua, K. Return to Farmland Investment in Alberta, 1964-1989, Project Report 93-08. 1993. Farming for the Future Project 91-0936.

Rahuma, A. A. Productivity in the Prairie Grain Sector. 1989. Edmonton, Canada, Unpublished Ph.D. Disertation, Department of Rural Economy, University of Alberta.

Ray, S.C. "A Translog Cost Function Analysis of U.S. Agriculture, 1939-77." *American Journal of Agricultural Economics* 64(1982):490-498.

Rosegrant, M.W. and R.E. Evenson. "Agricultural Productivity and Sources of Growth in South Asia." *American Journal of Agricultural Economics* 74(1992):757-761.

Sachs, J. and A. Warner, "The Curse of Natural Resources." *European Economic Review* 45(2001):827-838.

Salami, H. Production and Productivity Measurement, Iran. 1996. Edmonton, Canada, Unpublished Ph.D. Dissertation, Department of Rural Economy, University of Alberta.

Saskatchewan Agriculture, Food and Rural Revitalization. Agricultural Statistics. Various Years. Regina, Canada.

Saskatchewan Agriculture, Food and Rural Revitalization. Annual Report. Various Years. Regina, Canada.

Solow, R. "Technical Change and the Aggregate Production Function." *Review of Economics and Statistics* 39(1957):312-320.

Statistics Canada. Livestock Feed Requirements Study: 1999-2001, Catalogue no. 23-501. 2003. Ottawa, Canada.

Statistics Canada. Farm Cash Receipts, Catalogue no. 21-011. 2004a. Ottawa, Canada.

Statistics Canada. Farm Operating Expenses and Depreciation Charges, Catalogue no. 21-012. 2004b. Ottawa, Canada.

Statistics Canada. Value of Farm Capital, Catalogue no. 21-013. 2004c. Ottawa, Canada.

Statistics Canada. Cattle Statistics: 2005, vol.4 no.2, Catalogue no. 23-012. 2005a. Ottawa, Canada.

Statistics Canada. Hog Statistics: 2005, vol.4 no.4, Catalogue no. 23-010. 2005b. Ottawa, Canada.

Statistics Canada. Sheep Statistics: 2005, vol.4 no.2. 2005c. Ottawa, Canada.

Statistics Canada. Census of Agriculture. Various Years. Ottawa, Canada.

Statistics Canada. Census of Canada. Various Years. Ottawa, Canada.

Statistics Canada. Cereals and Oilseeds Review, Catalogue no. 22-007. Various Years. Ottawa, Canada.

Statistics Canada. Livestock Statistics, Catalogue no. 23-603. Various Years. Ottawa, Canada.

Statistics Canada. Various CANSIM and CANSIM II Data Series. Various Years. Ottawa, Canada.

Stevenson, R. "Measuring Technological Bias." *American Economic Review* 70(1980):162-173.

Thirtle, C. and P. Bottomley. "Total Factor Productivity in UK Agriculture, 1967-1990." *Journal of Agricultural Economics* 43(1992):381-400.

Thompson, G.D. "Choice of Flexible Functional Forms: Review and Appraisal." *Western Journal of Agricultural Economics* 13(1988):169-183.

Townsend, R. and C. Thirtle. "Is Livestock Research Unproductive? Separating Health Maintenance From Improvement Research." *Agricultural Economics* 25(2001):177-189.

United States Department of Agriculture. Measurement of U.S. Agricultural Productivity: A Review of Current Statistics and Proposals for Change. 1980. Washington, DC.

United States Department of Agriculture. Agricultural Statistics. Various Years. Washington, DC.

Varian, H.R. *Microeconomic Analysis.* New York: W.W. Norton & Company, 1992.

Veeman, T. S. Economic Consequences and Policy Implications of the "Green Revolution" in India with Particular Emphasis on Water Resources in Punjab. 1975. Berkley, Unpublished Ph.D. Dissertation, University of California.

Veeman, T. S. The Relative Roles of Technical Change and Scale Impacts in Estimated Productivity Growth in Canadian Prairie Agriculture, 1948-1994. XXIII International Conference of Agricultural Economists, Sacramento, California. 1997. Department of Rural Economy, University of Alberta.

Veeman, T. S. and Fantino, A. A. Productivity Growth in Western Canadian Agriculture: Empirical Measurement, Underlying Causal Influences and Policy Implications, FFF Project 82-0064. 1985. Departments of Rural Economy/Economics, University of Alberta.

Veeman, T. S., Fantino, A. A., and Peng, Y. Capital Formation, Technical Change, and Profitability in Prairie Agriculture, Project Report 95-09. 1995. Department of Rural Economy, University of Alberta, Alberta Agricultural Research Institute Project No. 920199.

Veeman, T. S., Fantino, A. A., and Peng, Y. Productivity in the Agri-food Sector: The Case of Primary Agriculture and Processing in Alberta. 1998 Canadian Agricultural Economics Society Annual Meeting, Vancouver, Canada. 1998. Department of Rural Economy, University of Alberta.

Veeman, T. S., Fantino, A. A., and Rahuma, A. A. Productivity Growth and Profitability in the Prairie Grains Sector, Project Report 89-08. 1989. Department of Rural Economy, University of Alberta, Final Report to Farming for the Future Council, ARCA Project 84-0365.

Veeman, T. S., Peng, Y., and Fantino, A. A. Science Technology, and Competitiveness in Alberta's Agriculture and Food Sector, Project Report 97-04. 1997. Department of Rural Economy, University of Alberta, Alberta Agricultural Research Institute Project No. 940519.

Weaver, R. " Measuring Productivity of Environmentally Interactive Technologies: The Case of Agriculture and the Environment." *American Journal of Agricultural Economics* 80(1998):595-599.

Widmer, L., G. Fox, and G. Brinkman. "The Rate of Return to Agricultural Research in a Small Country: the Case of Beef Cattle Research in Canada." *Canadian Journal of Agricultural Economics* 36(1988):23-35.

Wooldridge, J. *Introductory Econometrics: a Modern Approach.* 2nd ed. Cincinnati, Ohio: South-Western College Pub., 2003.

Yotopoulos, P. and J. Nugent. *Economics of Development: Empirical Investigations.* New York, New York: Harper & Row, 1976.

APPENDIX A: MULTI-OUT AND SINGLE-OUTPUT PRODUCTION SCHEMATICS

Figure A.1 Crop and Livestock Multi-Output Schematic

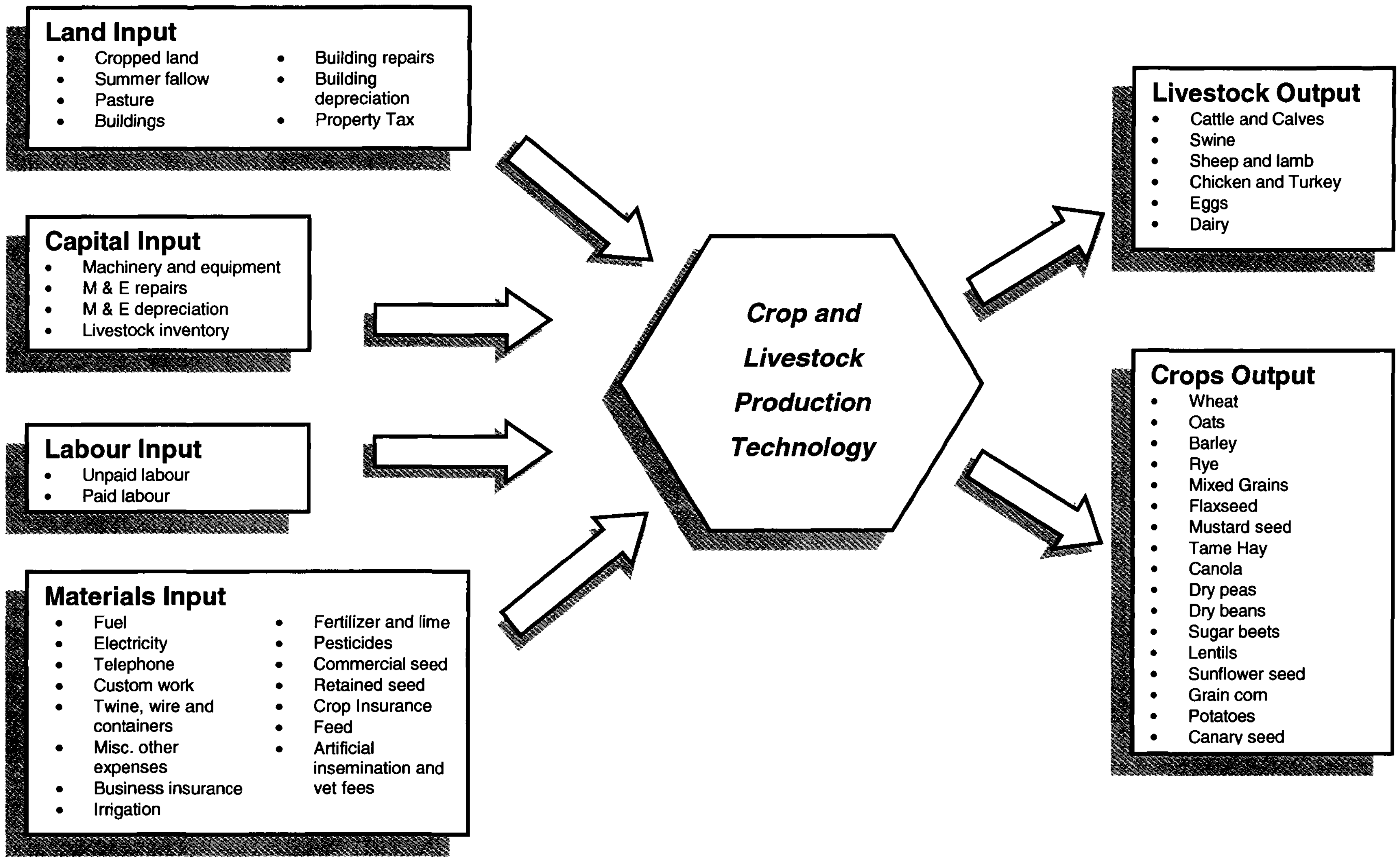


Figure A.2 Crop Single-Output Schematic

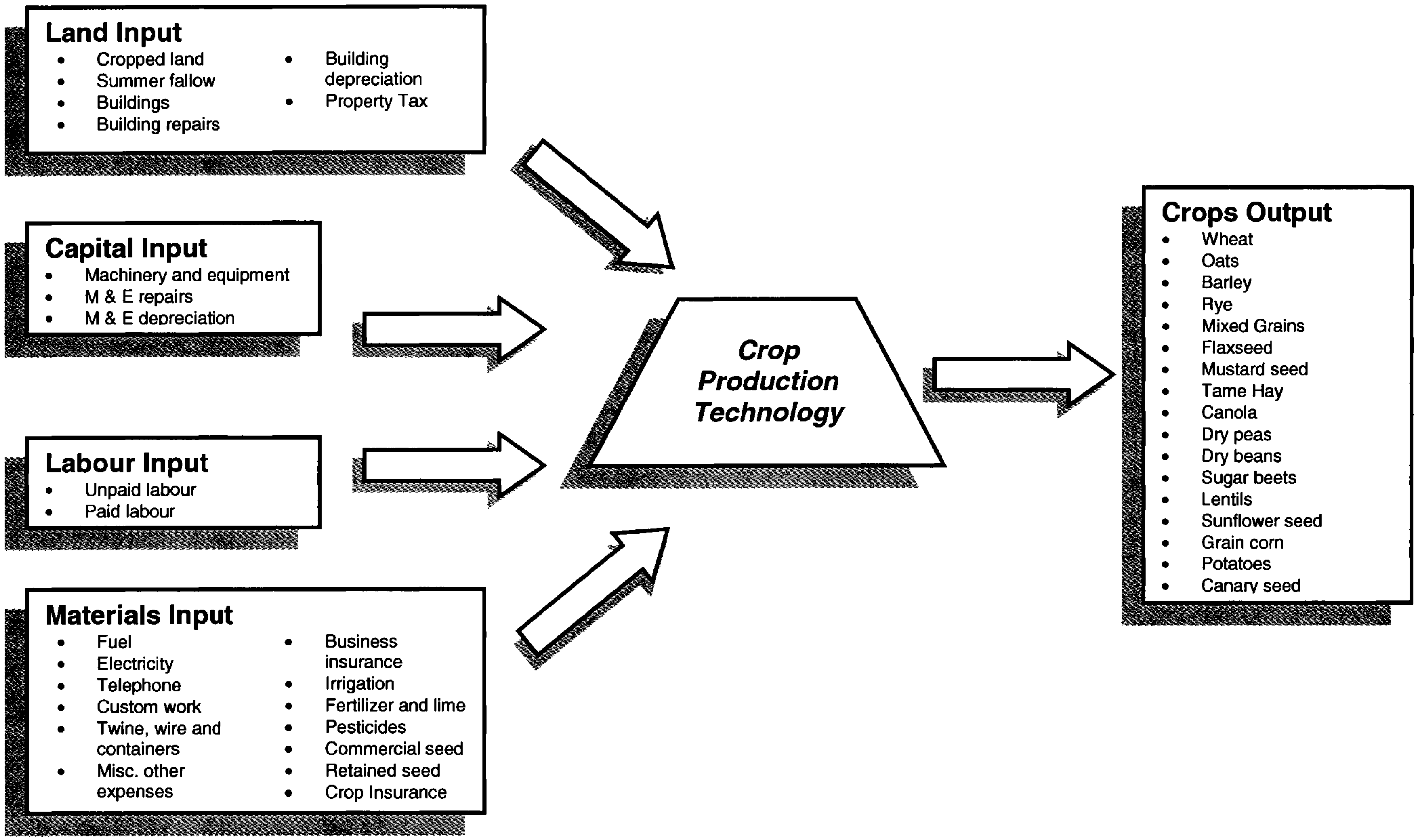
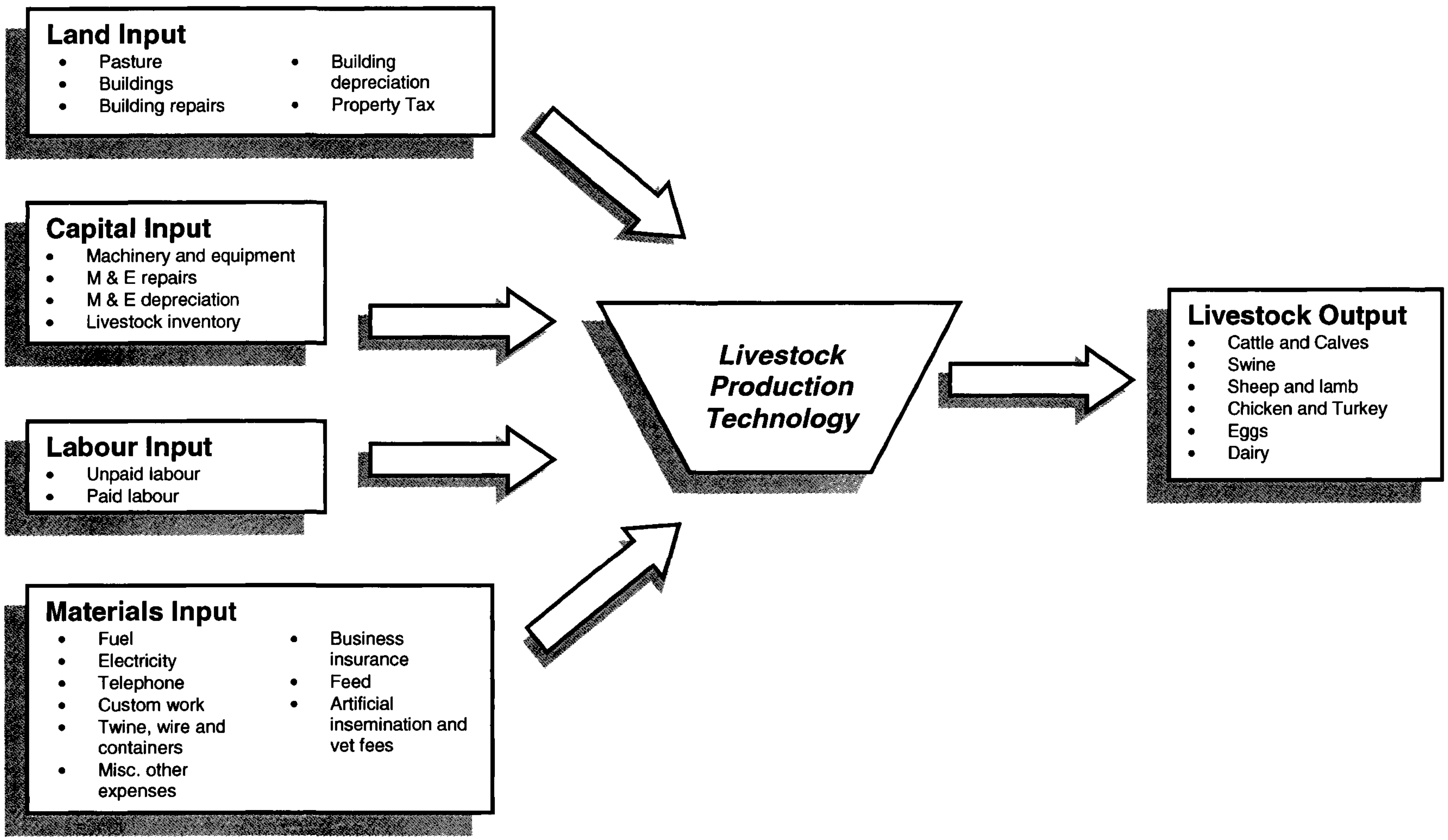


Figure A.3 Livestock Single-Output Schematic



APPENDIX B: DATA

Table B.1 Alberta Crop Input/Output Data (1 of 2)

	Input Cost Shares				Total Cost	Input Price Indexes (1970=100)				Input Quantity Indexes (1970=100)				Crop Output Indexes		Total Revenue
Year	Capital	Land	Labour	Materials	('000 $)	Capital	Land	Labour	Materials	Capital	Land	Labour	Materials	Price	Quantity	('000 $)
1940	0.1554	0.1265	0.5451	0.1730	125,187	27.57	17.76	17.24	47.16	42.34	74.00	193.71	32.72	44.49	58.33	139,992
1941	0.1615	0.1264	0.5361	0.1760	128,811	29.30	17.99	20.93	51.63	42.60	75.13	161.45	31.29	53.85	35.96	104,164
1942	0.1341	0.1002	0.5993	0.1664	166,740	32.39	18.65	25.79	56.03	41.41	74.35	189.62	35.30	62.92	72.19	244,422
1943	0.1323	0.0965	0.5934	0.1777	181,674	34.86	19.82	32.64	67.75	41.38	73.44	161.60	33.96	92.67	45.03	224,540
1944	0.1220	0.0932	0.6065	0.1783	203,322	36.96	21.01	36.15	70.55	40.28	74.83	166.89	36.62	98.66	45.55	242,348
1945	0.1226	0.0923	0.5966	0.1885	220,606	37.98	22.22	38.64	77.09	42.72	76.07	166.67	38.43	114.79	36.47	226,123
1946	0.1191	0.0856	0.6177	0.1776	249,267	39.77	23.09	39.88	78.64	44.79	76.70	188.93	40.11	117.84	51.39	326,977
1947	0.1274	0.0875	0.5924	0.1927	265,992	43.72	24.74	43.15	85.48	46.50	78.09	178.67	42.73	137.24	46.32	340,451
1948	0.1448	0.0941	0.5841	0.1770	285,378	49.77	28.89	46.50	81.56	49.81	77.18	175.38	44.14	123.43	51.59	341,024
1949	0.1695	0.1062	0.5317	0.1927	286,954	53.59	31.27	48.24	86.13	54.44	80.86	154.73	45.75	131.17	38.73	277,289
1950	0.1845	0.1005	0.5265	0.1885	313,510	56.33	32.33	48.01	86.46	61.60	80.89	168.24	48.71	127.90	48.74	340,224
1951	0.1901	0.0926	0.5215	0.1959	351,955	62.63	33.39	53.06	87.11	64.08	81.01	169.24	56.40	125.43	72.74	498,961
1952	0.1858	0.0855	0.5435	0.1852	390,791	65.54	34.05	59.50	87.90	66.48	81.46	174.66	58.67	120.01	80.33	527,353
1953	0.1956	0.0948	0.5285	0.1812	398,034	64.32	37.72	62.37	84.05	72.64	83.00	165.02	61.14	101.33	76.26	422,673
1954	0.2198	0.1141	0.4678	0.1983	354,499	63.23	40.31	59.48	85.13	73.92	83.31	136.40	58.86	102.57	51.36	288,080
1955	0.2056	0.1043	0.4869	0.2032	379,714	62.99	39.55	58.42	85.59	74.37	83.09	154.85	64.24	108.43	67.62	401,158
1956	0.2056	0.1068	0.4815	0.2061	386,361	65.64	41.40	60.55	83.22	72.62	82.73	150.32	68.19	96.76	75.13	397,068
1957	0.2267	0.1145	0.4367	0.2220	365,811	68.35	42.79	63.13	84.23	72.81	81.26	123.82	68.73	96.47	55.10	290,148
1958	0.2358	0.1219	0.4100	0.2323	368,924	70.42	45.20	62.22	86.63	74.13	82.56	118.96	70.49	101.94	59.49	331,034
1959	0.2317	0.1233	0.4120	0.2330	400,752	73.48	48.48	64.64	87.34	75.80	84.61	124.99	76.18	102.45	65.36	365,562
1960	0.2300	0.1260	0.4144	0.2296	420,082	75.20	51.79	66.31	90.34	77.09	84.85	128.44	76.08	110.88	63.86	386,214
1961	0.2340	0.1345	0.3881	0.2434	424,917	76.49	54.52	66.16	95.26	78.00	87.03	121.95	77.37	130.02	56.70	401,984
1962	0.2319	0.1365	0.3953	0.2363	446,929	78.81	56.74	69.04	94.59	78.89	89.22	125.20	79.58	120.86	69.01	454,981
1963	0.2275	0.1373	0.3963	0.2389	479,879	79.76	60.55	70.86	95.43	82.13	90.32	131.30	85.61	120.65	83.20	547,807
1964	0.2333	0.1453	0.3726	0.2488	501,391	82.50	66.25	72.53	95.81	85.07	91.28	126.01	92.79	121.20	77.17	509,811
1965	0.2326	0.1544	0.3719	0.2411	543,293	84.03	74.20	76.02	98.03	90.21	93.81	130.06	95.24	122.54	90.08	601,546
1966	0.2335	0.1598	0.3641	0.2426	586,813	87.10	81.86	81.18	99.32	94.40	95.05	128.77	102.15	126.01	105.75	726,430
1967	0.2409	0.1703	0.3356	0.2532	609,202	89.86	90.13	87.86	99.87	98.00	95.51	113.87	110.07	118.66	84.42	546,224
1968	0.2406	0.1792	0.3271	0.2530	648,347	94.14	99.45	91.65	99.90	99.42	96.99	113.23	117.01	108.20	94.02	554,338
1969	0.2551	0.1916	0.3209	0.2324	632,789	97.08	102.65	97.27	98.94	99.77	98.03	102.15	105.91	96.00	97.18	507,811
1970	0.2638	0.1907	0.3235	0.2221	631,857	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	545,177
1971	0.2570	0.1786	0.3200	0.2443	660,468	101.92	98.52	105.77	101.07	99.94	99.40	97.78	113.77	97.76	101.61	543,462
1972	0.2408	0.1683	0.3422	0.2487	765,111	106.26	104.17	113.66	113.60	104.04	102.57	112.70	119.38	144.87	107.64	854,017
1973	0.2231	0.1582	0.3495	0.2692	962,336	111.71	121.18	128.68	143.14	115.28	104.26	127.89	129.00	291.68	104.90	1,675,042

Table B.1 Cont'd Alberta Crop Input/Output Data (2 of 2)

	Input Cost Shares				Total Cost	Input Price Indexes (1970=100)				Input Quantity Indexes (1970=100)				Crop Output Indexes		Total Revenue
Year	Capital	Land	Labour	Materials	('000 $)	Capital	Land	Labour	Materials	Capital	Land	Labour	Materials	Price	Quantity	('000 $)
1974	0.2405	0.1626	0.3323	0.2646	1,155,917	128.23	150.47	151.90	161.23	130.07	103.69	123.72	135.19	284.69	94.00	1,463,190
1975	0.2350	0.1606	0.3514	0.2530	1,506,347	148.49	190.29	193.17	186.48	143.02	105.53	134.07	145.65	268.47	113.09	1,661,317
1976	0.2432	0.1728	0.3410	0.2431	1,713,430	160.62	230.51	214.11	199.47	155.65	106.60	133.51	148.79	234.69	121.36	1,560,931
1977	0.2642	0.1950	0.2938	0.2470	1,755,666	171.03	268.00	231.26	200.81	162.71	106.01	109.14	153.91	222.49	117.64	1,424,210
1978	0.2740	0.2128	0.2434	0.2699	1,901,138	185.37	313.64	245.68	211.64	168.60	107.05	92.15	172.75	245.15	139.25	1,857,486
1979	0.2710	0.2364	0.2103	0.2823	2,202,507	210.61	400.30	263.43	235.84	170.06	107.94	86.02	187.90	307.63	135.26	2,263,732
1980	0.2641	0.2567	0.2035	0.2757	2,673,650	243.46	524.79	287.71	277.37	174.02	108.54	92.55	189.37	358.87	152.90	2,988,449
1981	0.2618	0.2588	0.1794	0.3001	3,156,523	279.50	614.27	303.79	323.72	177.36	110.36	91.20	208.55	314.79	164.21	2,816,117
1982	0.2709	0.2607	0.1691	0.2993	3,304,526	296.19	643.00	320.18	333.14	181.32	111.22	85.38	211.58	279.74	160.73	2,449,203
1983	0.2747	0.2395	0.1666	0.3191	3,450,868	298.78	616.61	333.38	339.21	190.36	111.26	84.40	231.36	318.40	163.42	2,834,984
1984	0.2698	0.2208	0.1736	0.3359	3,520,527	303.34	566.54	338.09	349.74	187.84	113.86	88.46	240.95	322.72	145.77	2,566,234
1985	0.2694	0.1978	0.2127	0.3201	3,672,970	301.19	524.98	345.52	351.48	197.07	114.86	110.65	238.40	271.77	135.03	1,988,974
1986	0.2964	0.1948	0.1972	0.3116	3,443,519	298.79	484.04	351.59	327.72	204.94	115.02	94.49	233.36	195.37	200.37	2,145,207
1987	0.2997	0.1947	0.2037	0.3019	3,244,128	300.17	447.82	362.67	316.63	194.32	117.08	89.15	220.45	222.97	186.30	2,275,940
1988	0.2832	0.1797	0.2270	0.3101	3,380,508	302.54	428.41	377.87	332.03	189.84	117.70	99.38	224.98	302.59	190.02	3,149,657
1989	0.2838	0.1755	0.2195	0.3212	3,495,198	312.40	436.58	399.85	339.79	190.48	116.64	93.88	235.47	260.18	187.61	2,675,164
1990	0.2859	0.1809	0.2211	0.3121	3,539,423	327.22	463.53	418.84	343.25	185.56	114.62	91.42	229.34	228.27	196.74	2,462,156
1991	0.2792	0.1801	0.2386	0.3020	3,568,009	330.20	466.76	450.83	338.45	181.01	114.29	92.41	226.89	209.54	200.87	2,308,157
1992	0.2677	0.1698	0.2629	0.2997	3,690,686	327.86	457.04	532.32	344.17	180.78	113.78	89.19	229.01	233.96	172.69	2,215,492
1993	0.2572	0.1611	0.2678	0.3139	3,942,108	338.84	458.57	577.24	357.38	179.51	114.91	89.49	246.79	245.28	217.61	2,925,038
1994	0.2589	0.1606	0.2348	0.3458	4,151,855	359.60	479.84	551.75	394.81	179.32	115.31	86.44	259.14	291.00	206.86	3,298,941
1995	0.2450	0.1601	0.2397	0.3552	4,580,844	371.40	524.97	574.81	455.03	181.31	115.96	93.47	254.80	360.35	222.36	4,392,106
1996	0.2462	0.1643	0.2301	0.3594	4,816,605	384.05	576.70	603.95	456.70	185.27	113.86	89.81	270.12	311.53	214.66	3,665,022
1997	0.2501	0.1737	0.2177	0.3585	4,896,312	394.73	620.28	620.33	446.32	186.13	113.83	84.06	280.27	300.77	199.65	3,291,295
1998	0.2519	0.1818	0.2161	0.3502	4,988,316	397.50	661.51	609.71	421.85	189.63	113.78	86.52	295.12	280.01	206.80	3,174,306
1999	0.2620	0.1929	0.1874	0.3577	4,968,283	401.02	697.65	583.93	405.62	194.77	114.00	78.02	312.22	243.14	240.77	3,208,976
2000	0.2667	0.2064	0.1541	0.3728	4,923,633	437.38	726.97	616.02	433.40	180.11	116.04	60.27	301.81	242.94	206.51	2,752,768
2001	0.2719	0.2100	0.1320	0.3861	4,947,145	459.06	761.03	651.27	493.80	175.83	113.28	49.07	275.63	299.70	173.30	2,848,351
2002	0.2714	0.2172	0.1271	0.3842	4,987,250	451.20	795.55	662.84	472.61	180.00	113.02	46.81	288.93	362.51	112.75	2,240,400
2003	0.2490	0.2026	0.1549	0.3934	5,461,722	494.87	819.67	683.36	539.02	164.91	112.07	60.57	284.09	318.02	214.06	3,731,710
2004	0.2402	0.2033	0.1655	0.3910	5,622,422	496.18	847.55	718.08	515.01	163.27	111.94	63.41	304.23	309.92	251.20	4,268,959

Table B.2 Alberta Livestock Input/Output Data (1 of 2)

	Input Cost Shares				Total Cost	Input Price Indexes (1970=100)				Input Quantity Indexes (1970=100)				Crop Output Indexes		Total Revenue
Year	Capital	Land	Labour	Materials	('000 $)	Capital	Land	Labour	Materials	Capital	Land	Labour	Materials	Price	Quantity	('000 $)
1940	0.0903	0.0805	0.4005	0.4288	119,041	28.98	18.64	17.24	39.56	52.96	89.96	148.99	46.43	30.97	66.61	111,435
1941	0.0689	0.0591	0.4038	0.4682	162,635	30.27	18.71	20.93	51.76	52.86	89.94	169.04	52.94	31.48	68.85	117,077
1942	0.0685	0.0561	0.3434	0.5320	175,497	35.15	19.52	25.79	54.97	48.82	88.37	125.90	61.11	39.59	72.25	154,477
1943	0.0580	0.0425	0.3655	0.5340	244,923	39.37	20.84	32.64	72.43	51.53	87.55	147.71	64.97	46.99	79.36	201,430
1944	0.0585	0.0415	0.3379	0.5621	269,652	40.11	22.17	36.15	82.01	56.14	88.45	135.76	66.51	45.63	73.88	182,059
1945	0.0620	0.0456	0.3619	0.5306	263,008	41.19	23.53	38.64	85.71	56.51	89.25	132.67	58.58	46.82	63.14	159,656
1946	0.0704	0.0545	0.3286	0.5465	235,853	44.47	24.54	39.88	93.03	53.34	91.64	104.70	49.85	52.71	53.51	152,353
1947	0.0681	0.0528	0.3381	0.5410	266,721	49.65	26.39	43.15	110.68	52.23	93.50	112.57	46.91	60.26	57.01	185,552
1948	0.0802	0.0615	0.3674	0.4908	265,106	58.18	30.83	46.50	103.29	52.22	92.67	112.83	45.33	74.07	47.91	191,941
1949	0.0779	0.0565	0.3783	0.4873	313,115	61.50	33.16	48.24	125.87	56.66	93.45	132.25	43.62	75.83	53.27	218,408
1950	0.0985	0.0632	0.3557	0.4826	285,776	64.62	34.38	48.01	116.89	62.20	92.00	114.05	42.46	79.63	47.92	206,303
1951	0.1095	0.0606	0.3435	0.4865	306,920	76.19	35.37	53.06	112.65	62.99	92.02	107.02	47.70	103.70	50.16	281,462
1952	0.1154	0.0597	0.3307	0.4942	318,243	70.39	36.06	59.50	111.41	74.53	92.23	95.29	50.79	79.07	59.34	253,913
1953	0.1132	0.0660	0.3615	0.4592	321,101	67.14	39.71	62.37	98.92	77.33	93.49	100.26	53.64	72.01	59.34	231,166
1954	0.0978	0.0613	0.3936	0.4473	354,129	65.50	41.59	59.48	100.07	75.53	91.37	126.22	56.96	69.28	67.84	254,240
1955	0.1000	0.0626	0.3189	0.5185	341,618	63.96	41.24	58.42	103.80	76.30	90.80	100.43	61.41	65.12	67.77	238,762
1956	0.1002	0.0652	0.3295	0.5050	341,274	65.46	43.29	60.55	94.40	74.66	89.99	100.05	65.70	64.42	70.15	244,449
1957	0.0925	0.0577	0.3799	0.4700	382,497	68.59	44.75	63.13	92.82	73.67	86.29	123.98	69.69	68.30	76.31	281,928
1958	0.0935	0.0566	0.3497	0.5002	410,046	72.42	47.56	62.22	97.85	75.62	85.45	124.16	75.42	75.13	82.97	337,261
1959	0.1036	0.0614	0.3382	0.4968	399,224	73.25	50.62	64.64	93.05	80.69	84.75	112.50	76.70	72.53	80.78	317,034
1960	0.1031	0.0637	0.3152	0.5179	405,202	73.37	54.02	66.31	97.28	81.35	83.71	103.75	77.63	70.41	78.29	298,348
1961	0.0934	0.0604	0.2868	0.5593	458,202	74.85	56.48	66.16	118.19	81.66	85.82	107.01	78.03	72.14	87.34	340,930
1962	0.1019	0.0671	0.2910	0.5399	439,249	78.81	58.74	69.04	107.65	81.16	87.83	99.73	79.28	78.43	82.09	348,434
1963	0.1111	0.0739	0.2782	0.5367	422,937	77.82	62.45	70.86	106.29	86.26	87.67	89.44	76.85	74.70	87.69	354,479
1964	0.1037	0.0718	0.2549	0.5697	485,078	77.15	67.94	72.53	112.47	93.13	89.70	91.81	88.41	69.61	94.72	356,831
1965	0.1088	0.0800	0.2444	0.5668	484,897	81.10	75.61	76.02	112.31	92.93	89.81	83.97	88.06	76.73	89.04	369,732
1966	0.1086	0.0849	0.2381	0.5684	508,771	87.05	82.74	81.18	116.40	90.68	91.39	80.39	89.39	87.00	91.23	429,620
1967	0.1078	0.0890	0.2769	0.5263	545,752	88.89	90.92	87.86	110.60	94.58	93.53	92.64	93.45	87.42	91.72	434,020
1968	0.1104	0.0978	0.2773	0.5145	552,068	91.22	99.87	91.65	110.95	95.41	94.67	89.98	92.12	86.92	90.85	427,425
1969	0.1173	0.1043	0.3269	0.4515	550,233	97.74	102.65	97.27	96.82	94.34	97.89	99.60	92.33	98.66	92.20	492,344
1970	0.1185	0.0967	0.3143	0.4705	590,670	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	541,256
1971	0.1130	0.0952	0.3260	0.4658	622,473	100.39	101.61	105.77	100.10	100.06	102.11	103.35	104.24	98.51	108.87	581,224
1972	0.1009	0.0897	0.2490	0.5604	750,673	109.47	109.11	113.66	141.40	98.87	108.02	88.57	107.06	113.10	106.70	653,991
1973	0.0759	0.0684	0.1474	0.7082	1,201,979	129.77	127.02	128.68	240.54	100.45	113.39	74.17	127.35	151.25	110.79	908,163

Table B.2 Cont'd Alberta Livestock Input/Output Data (2 of 2)

	Input Cost Shares				Total Cost	Input Price Indexes (1970=100)				Input Quantity Indexes (1970=100)				Crop Output Indexes		Total Revenue
Year	Capital	Land	Labour	Materials	('000 $)	Capital	Land	Labour	Materials	Capital	Land	Labour	Materials	Price	Quantity	('000 $)
1974	0.0794	0.0766	0.1699	0.6741	1,360,957	140.91	155.41	151.90	250.06	109.60	117.43	81.98	132.02	155.81	112.00	945,860
1975	0.0814	0.0953	0.1954	0.6279	1,371,877	153.26	190.59	193.17	247.55	104.09	120.12	74.75	125.21	157.73	104.64	894,481
1976	0.0881	0.1150	0.2186	0.5784	1,340,461	158.36	226.02	214.11	223.57	106.52	119.39	73.71	124.78	151.97	101.45	835,507
1977	0.1011	0.1338	0.2197	0.5454	1,264,543	160.64	259.06	231.26	206.66	113.69	114.38	64.70	120.09	141.18	109.01	833,993
1978	0.1131	0.1464	0.1982	0.5422	1,320,691	192.12	300.39	245.68	217.93	111.08	112.73	57.40	118.24	200.81	106.80	1,162,570
1979	0.1139	0.1475	0.1653	0.5733	1,668,546	229.92	381.91	263.43	275.60	118.04	112.85	56.41	124.89	259.08	108.92	1,529,700
1980	0.1136	0.1575	0.1325	0.5964	1,985,266	247.17	483.67	287.71	331.39	130.30	113.23	49.25	128.57	254.29	112.10	1,545,243
1981	0.1197	0.1870	0.1493	0.5440	1,947,547	270.42	553.53	303.79	291.84	123.13	115.20	51.57	130.63	261.75	112.87	1,601,398
1982	0.1216	0.2010	0.1644	0.5129	1,880,083	275.75	575.69	320.18	268.65	118.46	114.93	52.01	129.17	254.20	113.13	1,558,567
1983	0.1149	0.1869	0.1474	0.5508	1,921,425	277.42	555.36	333.38	301.86	113.65	113.22	45.77	126.16	254.91	114.05	1,575,603
1984	0.1016	0.1645	0.1641	0.5697	2,026,684	287.05	512.90	338.09	320.38	102.46	113.83	53.00	129.69	269.20	114.65	1,672,680
1985	0.0929	0.1517	0.2409	0.5145	2,041,318	282.75	480.25	345.52	288.12	95.84	112.88	76.65	131.18	263.13	114.58	1,633,949
1986	0.1195	0.1726	0.2432	0.4648	1,711,970	290.38	449.69	351.59	225.03	100.63	115.03	63.78	127.23	280.14	109.26	1,658,765
1987	0.1239	0.1636	0.2397	0.4728	1,823,613	300.01	425.49	362.67	233.85	107.59	122.75	64.92	132.69	299.16	118.01	1,913,343
1988	0.1204	0.1395	0.1943	0.5458	2,132,086	298.03	410.48	377.87	302.62	123.00	126.89	59.06	138.37	292.09	124.11	1,964,796
1989	0.1314	0.1410	0.2193	0.5083	2,225,120	303.93	422.29	399.85	279.13	137.40	130.09	65.75	145.80	293.24	128.75	2,046,270
1990	0.1421	0.1501	0.2418	0.4660	2,296,513	314.48	445.77	418.84	254.06	148.28	135.38	71.41	151.57	298.28	132.73	2,145,812
1991	0.1410	0.1472	0.2704	0.4414	2,370,322	313.37	444.30	450.83	235.42	152.33	137.52	76.59	159.91	291.83	137.84	2,180,209
1992	0.1275	0.1303	0.2921	0.4500	2,659,129	313.72	434.30	532.32	257.03	154.39	139.74	78.61	167.52	295.64	142.36	2,281,139
1993	0.1353	0.1327	0.2860	0.4460	2,676,681	335.88	441.79	577.24	252.88	154.02	140.81	71.44	169.86	333.02	142.22	2,567,156
1994	0.1397	0.1311	0.2396	0.4896	2,909,631	345.26	466.36	551.75	282.16	168.16	143.21	68.07	181.66	327.65	157.00	2,788,219
1995	0.1244	0.1215	0.1932	0.5609	3,423,967	349.97	504.37	574.81	365.77	173.87	144.44	61.99	188.93	323.69	163.72	2,872,354
1996	0.1249	0.1347	0.2225	0.5179	3,409,359	354.61	547.84	603.95	329.75	171.53	146.79	67.64	192.70	317.93	167.35	2,883,777
1997	0.1264	0.1406	0.2249	0.5081	3,511,570	370.50	589.23	620.33	323.79	171.15	146.77	68.57	198.27	341.37	157.95	2,922,540
1998	0.1337	0.1480	0.2266	0.4917	3,524,059	364.39	619.35	609.71	303.07	184.76	147.41	70.56	205.72	323.18	161.67	2,832,879
1999	0.1439	0.1592	0.2018	0.4952	3,435,305	370.65	651.14	583.93	288.43	190.55	147.03	63.94	212.22	332.98	159.72	2,883,672
2000	0.1462	0.1602	0.1948	0.4987	3,587,437	408.33	671.89	616.02	291.47	183.52	149.78	61.11	220.89	372.29	172.27	3,477,392
2001	0.1379	0.1458	0.1534	0.5629	4,126,639	432.88	699.06	651.27	351.99	187.83	150.72	52.34	237.46	399.89	179.55	3,892,827
2002	0.1255	0.1350	0.1467	0.5928	4,572,167	409.47	727.85	662.84	414.64	200.19	148.50	54.49	235.22	360.91	181.58	3,553,175
2003	0.1313	0.1562	0.1511	0.5614	4,060,196	421.96	746.37	683.36	369.33	180.45	148.79	48.35	222.09	342.13	174.02	3,227,948
2004	0.1214	0.1631	0.1521	0.5634	4,020,828	416.94	781.23	718.08	355.12	167.20	146.99	45.88	229.54	330.08	178.53	3,193,691

Table B.3 Saskatchewan Crop Input/Output Data (1 of 2)

	Input Cost Shares				Total Cost	Input Price Indexes (1970=100)				Input Quantity Indexes (1970=100)				Crop Output Indexes		Total Revenue
Year	Capital	Land	Labour	Materials	('000 $)	Capital	Land	Labour	Materials	Capital	Land	Labour	Materials	Price	Quantity	('000 $)
1940	0.1454	0.1381	0.5328	0.1837	182,641	27.53	21.77	16.93	48.13	47.74	67.90	192.25	52.56	44.12	60.75	186,837
1941	0.1544	0.1429	0.5217	0.1809	185,008	29.26	22.15	19.73	51.42	48.32	69.92	163.66	49.08	49.54	39.23	134,010
1942	0.1303	0.1140	0.5784	0.1773	246,774	32.36	23.68	24.96	57.45	49.17	69.63	191.31	57.41	60.62	94.92	396,973
1943	0.1141	0.1006	0.5975	0.1879	290,308	34.89	24.54	31.45	71.15	46.98	69.72	184.53	57.78	90.24	58.46	363,963
1944	0.1019	0.0910	0.6273	0.1798	344,248	37.05	25.70	39.31	73.92	46.85	71.43	183.78	63.13	95.36	72.60	479,019
1945	0.1106	0.0941	0.5979	0.1973	355,732	38.16	27.33	40.40	82.98	51.05	71.80	176.13	63.77	114.25	50.39	398,414
1946	0.1154	0.0928	0.6012	0.1906	386,077	40.01	28.14	43.28	84.24	55.10	74.64	179.43	65.85	116.83	56.26	454,859
1947	0.1214	0.0925	0.5820	0.2041	415,442	43.97	29.51	45.99	91.60	56.76	76.27	175.88	69.80	132.76	50.51	460,981
1948	0.1445	0.1010	0.5621	0.1924	418,187	49.99	32.11	49.82	85.35	59.84	77.07	157.84	71.07	116.99	56.11	451,219
1949	0.1601	0.1019	0.5463	0.1916	438,290	53.86	34.00	51.15	90.23	64.50	76.98	156.60	70.17	125.12	49.20	430,438
1950	0.1739	0.1016	0.5403	0.1842	455,442	56.61	34.69	51.49	87.25	69.25	78.13	159.90	72.48	112.47	70.18	553,818
1951	0.1730	0.0980	0.5413	0.1877	501,966	62.90	36.11	57.01	89.27	68.32	79.81	159.47	79.57	115.51	88.30	715,181
1952	0.1678	0.0933	0.5618	0.1771	562,748	65.82	38.90	62.72	90.65	71.01	79.06	168.65	82.87	115.73	116.33	944,537
1953	0.1890	0.1013	0.5398	0.1700	558,928	64.54	40.62	64.52	84.12	80.99	81.64	156.45	85.14	96.34	100.42	678,688
1954	0.2140	0.1130	0.4880	0.1850	507,185	63.40	40.34	62.87	84.79	84.73	83.21	131.72	83.41	96.48	51.68	348,354
1955	0.1976	0.1065	0.5104	0.1855	545,514	63.14	40.97	62.21	87.46	84.50	83.08	149.74	87.21	104.23	94.60	689,369
1956	0.1992	0.1123	0.5031	0.1854	552,394	65.78	43.55	64.52	83.23	82.80	83.50	144.09	92.74	91.70	104.75	670,445
1957	0.2123	0.1201	0.4770	0.1907	530,443	68.44	44.61	69.14	82.06	81.42	83.66	122.42	92.93	86.35	67.46	406,440
1958	0.2119	0.1251	0.4621	0.2010	532,099	70.46	46.16	69.14	85.88	79.18	84.47	118.98	93.87	94.42	65.13	429,103
1959	0.2134	0.1281	0.4523	0.2063	543,846	73.52	48.04	69.80	87.42	78.12	84.95	117.90	96.73	98.45	68.69	472,429
1960	0.2085	0.1265	0.4553	0.2097	591,144	75.23	50.86	70.79	91.59	81.09	86.13	127.19	102.04	109.14	91.36	696,925
1961	0.2299	0.1438	0.4062	0.2200	548,784	76.52	53.42	73.76	96.92	81.62	86.57	101.11	93.92	123.76	36.75	318,290
1962	0.2095	0.1387	0.4484	0.2033	616,870	78.85	55.54	75.25	95.92	81.12	90.29	122.98	98.59	116.90	91.41	753,004
1963	0.2085	0.1430	0.4436	0.2049	659,244	79.79	59.95	75.58	97.47	85.26	92.17	129.44	104.47	120.79	126.08	1,073,345
1964	0.2242	0.1601	0.4031	0.2125	666,452	82.56	66.57	76.57	95.87	89.58	93.91	117.39	111.39	114.30	84.65	681,645
1965	0.2263	0.1675	0.3987	0.2075	735,221	84.06	74.87	80.69	98.50	97.97	96.37	121.55	116.73	119.89	107.74	909,339
1966	0.2236	0.1719	0.3965	0.2081	814,096	87.09	84.02	87.95	100.36	103.45	97.57	122.78	127.24	123.77	138.41	1,206,611
1967	0.2331	0.1902	0.3693	0.2075	829,996	89.78	94.21	95.21	99.62	106.66	98.16	107.69	130.30	113.43	86.84	693,944
1968	0.2382	0.2036	0.3582	0.2000	856,382	94.16	102.93	97.36	97.36	107.20	99.24	105.42	132.66	96.17	100.93	681,237
1969	0.2424	0.2069	0.3695	0.1812	848,899	97.09	103.12	99.67	98.11	104.89	99.80	105.29	118.20	92.39	127.38	825,646
1970	0.2512	0.2122	0.3716	0.1649	804,270	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	695,786
1971	0.2383	0.1984	0.3562	0.2072	854,756	101.84	99.03	104.13	100.14	98.97	100.32	97.83	133.31	92.71	139.12	900,666
1972	0.2318	0.1851	0.3549	0.2282	923,853	106.18	98.84	116.67	111.90	99.80	101.39	94.02	142.05	138.17	112.72	1,088,786
1973	0.2061	0.1597	0.3512	0.2830	1,151,767	111.69	104.39	133.66	154.71	105.21	103.24	101.24	158.81	305.70	122.35	2,615,922

Table B.3 Cont'd Saskatchewan Crop Input/Output Data (2 of 2)

	Input Cost Shares				Total Cost	Input Price Indexes (1970=100)				Input Quantity Indexes (1970=100)				Crop Output Indexes		Total Revenue
Year	Capital	Land	Labour	Materials	('000 $)	Capital	Land	Labour	Materials	Capital	Land	Labour	Materials	Price	Quantity	('000 $)
1974	0.2276	0.1628	0.3451	0.2645	1,351,502	128.26	123.57	164.36	169.00	118.72	104.32	94.95	159.43	297.49	101.58	2,110,326
1975	0.2510	0.1649	0.3369	0.2472	1,670,731	148.68	151.93	201.49	187.88	139.58	106.25	93.46	165.74	259.73	123.23	2,238,414
1976	0.2609	0.1721	0.3380	0.2289	1,979,840	160.90	186.68	235.64	193.95	158.90	106.96	95.01	176.18	220.91	148.32	2,294,625
1977	0.2676	0.1792	0.3293	0.2240	2,170,272	171.31	213.35	261.55	201.91	167.76	106.79	91.42	181.49	210.79	147.75	2,168,999
1978	0.2656	0.1815	0.3033	0.2496	2,496,674	185.74	246.59	272.94	220.93	176.71	107.67	92.83	212.62	260.57	160.38	2,913,927
1979	0.2689	0.1936	0.2704	0.2672	2,782,227	211.04	292.93	286.14	247.79	175.46	107.73	87.95	226.14	317.78	123.63	2,739,362
1980	0.2711	0.2150	0.2462	0.2677	3,152,754	244.03	370.50	308.25	289.72	173.33	107.22	84.24	219.59	373.41	124.49	3,247,231
1981	0.2710	0.2318	0.2209	0.2763	3,659,680	280.54	457.28	329.70	330.78	174.94	108.72	82.04	230.43	340.67	155.69	3,722,639
1982	0.2689	0.2333	0.2191	0.2788	4,039,756	297.22	512.09	357.59	341.17	180.87	107.84	82.79	248.84	303.24	180.01	3,840,956
1983	0.2630	0.2217	0.2207	0.2946	4,385,852	299.78	531.34	373.27	343.23	190.46	107.22	86.76	283.78	330.04	164.34	3,810,639
1984	0.2615	0.2146	0.2216	0.3023	4,496,347	304.22	518.93	394.39	355.58	191.26	108.98	84.51	288.21	324.89	140.03	3,192,002
1985	0.2634	0.2098	0.2125	0.3143	4,476,805	301.98	506.37	407.76	354.23	193.28	108.66	78.06	299.44	258.29	162.46	2,942,109
1986	0.2620	0.1995	0.2264	0.3122	4,434,358	298.88	474.06	418.15	330.30	192.39	109.32	80.31	315.94	205.32	214.68	3,084,360
1987	0.2691	0.1908	0.2424	0.2977	4,341,878	299.43	441.35	426.10	323.70	193.15	110.01	82.62	300.98	225.62	188.87	2,982,227
1988	0.2706	0.1865	0.2382	0.3047	4,202,137	301.62	415.69	442.82	327.52	186.56	110.49	75.61	294.75	321.64	104.00	2,340,730
1989	0.2662	0.1793	0.2326	0.3219	4,330,368	311.30	406.25	457.88	342.53	183.30	112.01	73.58	306.75	270.45	163.53	3,099,710
1990	0.2641	0.1803	0.2422	0.3134	4,285,275	326.29	405.67	462.06	352.29	171.69	111.58	75.14	287.42	212.05	214.19	3,182,187
1991	0.2694	0.1802	0.2428	0.3076	4,157,601	329.12	395.85	463.52	333.51	168.41	110.89	72.86	289.11	206.47	220.54	3,196,537
1992	0.2595	0.1661	0.2527	0.3217	4,325,748	326.62	384.79	516.17	340.69	170.11	109.38	70.85	307.98	218.21	197.55	3,024,339
1993	0.2559	0.1599	0.2555	0.3287	4,543,521	337.63	381.86	539.27	351.02	170.45	111.46	72.02	320.74	236.49	220.71	3,652,619
1994	0.2504	0.1545	0.2367	0.3584	4,885,636	358.46	395.82	567.66	379.38	168.91	111.75	68.16	347.92	305.85	224.32	4,800,087
1995	0.2434	0.1515	0.2242	0.3809	5,316,017	370.20	423.32	588.12	419.87	172.96	111.47	67.81	363.58	363.60	215.14	5,476,238
1996	0.2402	0.1473	0.2128	0.3997	5,698,477	382.81	450.84	602.64	433.60	176.99	109.10	67.31	395.99	311.57	253.31	5,514,941
1997	0.2434	0.1505	0.2054	0.4007	5,713,116	393.45	465.95	629.04	423.90	174.95	108.11	62.40	407.12	308.35	221.02	4,763,379
1998	0.2506	0.1547	0.2091	0.3855	5,724,101	396.19	481.88	633.79	400.25	179.17	107.71	63.19	415.66	274.38	242.98	4,656,833
1999	0.2615	0.1619	0.1902	0.3864	5,518,610	399.71	489.50	606.99	388.14	178.70	106.94	57.86	414.12	231.70	279.35	4,520,262
2000	0.2511	0.1593	0.1795	0.4101	5,622,700	435.78	493.64	640.35	410.70	160.34	106.32	52.73	423.26	249.28	270.42	4,709,322
2001	0.2559	0.1553	0.1515	0.4373	5,574,905	457.32	489.06	676.99	459.94	154.41	103.70	41.74	399.58	307.94	187.42	4,028,665
2002	0.2593	0.1627	0.1492	0.4289	5,456,791	449.78	493.92	689.02	441.50	155.69	105.30	39.52	399.60	331.93	148.94	3,449,339
2003	0.2485	0.1590	0.1431	0.4494	5,797,952	492.60	505.81	710.35	504.20	144.75	106.81	39.08	389.57	280.21	214.73	4,200,647
2004	0.2465	0.1572	0.1511	0.4452	5,975,223	493.98	518.09	746.44	487.05	147.54	106.26	40.48	411.72	276.78	258.07	4,987,555

Table B.4 Saskatchewan Livestock Input/Output Data (1 of 2)

	Input Cost Shares				Total Cost	Input Price Indexes (1970=100)				Input Quantity Indexes (1970=100)				Crop Output Indexes		Total Revenue
Year	Capital	Land	Labour	Materials	('000 $)	Capital	Land	Labour	Materials	Capital	Land	Labour	Materials	Price	Quantity	('000 $)
1940	0.1146	0.0751	0.4085	0.4018	102,459	27.53	21.77	16.93	41.92	57.36	83.97	206.12	55.51	30.33	94.51	86,179
1941	0.0900	0.0580	0.4501	0.4019	135,440	29.26	22.15	19.73	50.59	56.05	84.13	257.64	60.81	31.77	98.39	93,942
1942	0.0959	0.0596	0.3598	0.4847	141,746	32.36	23.68	24.96	53.70	56.50	84.67	170.36	72.32	41.24	117.60	145,756
1943	0.0844	0.0467	0.3394	0.5295	189,127	34.89	24.54	31.45	71.18	61.56	85.43	170.21	79.52	46.62	97.69	137,223
1944	0.0840	0.0464	0.3454	0.5243	213,418	37.05	25.70	39.31	76.01	65.04	91.47	156.36	83.20	44.83	120.31	162,501
1945	0.0871	0.0515	0.3680	0.4934	212,151	38.16	27.33	40.40	81.70	65.16	94.85	161.13	72.41	47.72	100.40	144,352
1946	0.0963	0.0575	0.3582	0.4880	199,849	40.01	28.14	43.28	88.06	64.68	96.98	137.92	62.60	53.84	84.02	136,315
1947	0.0972	0.0565	0.3352	0.5112	217,608	43.97	29.51	45.99	107.93	64.67	98.86	132.23	58.26	60.19	74.78	135,664
1948	0.1074	0.0585	0.4211	0.4130	231,350	49.99	32.11	49.82	98.89	66.86	100.04	163.05	54.61	80.21	78.76	190,453
1949	0.1208	0.0580	0.3908	0.4303	239,252	53.86	34.00	51.15	113.47	72.19	96.97	152.43	51.28	80.32	70.51	170,747
1950	0.1515	0.0631	0.3711	0.4143	217,819	56.61	34.69	51.49	103.71	78.41	94.04	130.93	49.18	85.45	70.68	182,137
1951	0.1638	0.0619	0.3445	0.4297	233,385	62.90	36.11	57.01	104.68	81.75	95.07	117.61	54.15	104.14	67.02	210,578
1952	0.1921	0.0688	0.2746	0.4645	221,183	65.82	38.90	62.72	100.59	86.83	92.84	80.77	57.72	78.35	74.01	174,934
1953	0.1914	0.0716	0.3275	0.4095	230,749	64.54	40.62	64.52	91.25	92.03	96.55	97.68	58.53	71.29	78.27	168,294
1954	0.1617	0.0590	0.4119	0.3674	267,648	63.40	40.34	62.87	92.57	91.80	92.88	146.22	60.05	68.37	78.48	161,803
1955	0.1851	0.0687	0.2840	0.4622	232,773	63.14	40.97	62.21	94.21	91.74	92.75	88.61	64.55	67.31	80.08	162,560
1956	0.1866	0.0716	0.2936	0.4482	238,190	65.78	43.55	64.52	87.33	90.86	92.96	90.39	69.09	65.25	85.78	168,797
1957	0.1610	0.0587	0.3842	0.3961	285,908	68.44	44.61	69.14	88.34	90.44	89.35	132.48	72.45	67.41	90.49	183,923
1958	0.1650	0.0585	0.3631	0.4134	295,696	70.46	46.16	69.14	90.03	93.15	89.02	129.48	76.73	74.24	87.16	195,267
1959	0.1798	0.0618	0.3453	0.4130	293,213	73.52	48.04	69.80	90.68	96.46	89.61	120.97	75.47	72.98	91.62	201,815
1960	0.2060	0.0703	0.2765	0.4473	266,890	75.23	50.86	70.79	90.84	98.26	87.53	86.91	74.28	71.00	90.19	193,281
1961	0.1534	0.0564	0.3664	0.4238	351,741	76.52	53.42	73.76	109.20	94.82	88.23	145.71	77.14	72.77	89.41	196,367
1962	0.1895	0.0756	0.2736	0.4612	281,390	78.85	55.54	75.25	98.78	90.96	90.98	85.31	74.26	77.98	91.39	215,102
1963	0.2045	0.0903	0.2194	0.4857	262,632	79.79	59.95	75.58	96.89	90.53	93.95	63.59	74.41	79.07	89.74	214,186
1964	0.1722	0.0845	0.2513	0.4920	322,329	82.56	66.57	76.57	105.40	90.41	97.13	88.23	85.03	75.73	94.22	215,389
1965	0.1796	0.0987	0.2216	0.5001	317,436	84.06	74.87	80.69	106.90	91.21	99.37	72.68	83.94	77.84	96.53	226,659
1966	0.1910	0.1113	0.1932	0.5045	318,464	87.09	84.02	87.95	107.56	93.93	100.18	58.33	84.42	86.85	90.84	237,971
1967	0.1776	0.1090	0.2746	0.4388	363,827	89.78	94.21	95.21	103.10	96.82	99.98	87.49	87.51	87.10	93.55	245,799
1968	0.1846	0.1183	0.2825	0.4146	362,110	94.16	102.93	97.36	99.75	95.45	98.85	87.62	85.06	89.43	91.50	246,835
1969	0.1930	0.1193	0.2826	0.4052	362,411	97.09	103.12	99.67	95.44	96.86	99.53	85.67	86.97	100.45	95.45	289,167
1970	0.1799	0.1019	0.2901	0.4281	413,324	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	301,600
1971	0.1761	0.1035	0.2685	0.4519	412,670	101.84	99.03	104.13	95.90	95.98	102.40	88.73	109.91	104.06	112.07	351,955
1972	0.1501	0.0903	0.2379	0.5216	493,800	106.18	98.84	116.67	128.45	93.87	107.17	83.98	113.34	120.77	115.96	422,688
1973	0.1116	0.0692	0.1171	0.7021	735,942	111.69	104.39	133.66	222.99	98.88	115.81	53.77	130.97	160.92	116.77	567,211

Table B.4 Cont'd Saskatchewan Livestock Input/Output Data (2 of 2)

	Input Cost Shares				Total Cost	Input Price Indexes (1970=100)				Input Quantity Indexes (1970=100)				Crop Output Indexes		Total Revenue
Year	Capital	Land	Labour	Materials	('000 $)	Capital	Land	Labour	Materials	Capital	Land	Labour	Materials	Price	Quantity	('000 $)
1974	0.1175	0.0774	0.1434	0.6617	812,149	128.26	123.57	164.36	222.80	100.07	120.78	59.10	136.32	151.46	121.68	556,280
1975	0.1228	0.0949	0.1573	0.6250	828,089	148.68	151.93	201.49	225.18	91.99	122.78	53.91	129.91	167.95	108.19	548,466
1976	0.1450	0.1262	0.1400	0.5888	748,291	160.90	186.68	235.64	202.61	90.67	120.14	37.07	122.91	136.16	89.10	365,792
1977	0.1531	0.1401	0.1832	0.5236	731,128	171.31	213.35	261.55	187.18	87.85	114.04	42.70	115.60	135.17	106.51	434,356
1978	0.1576	0.1525	0.1803	0.5096	774,028	185.74	246.59	272.94	200.47	88.30	113.70	42.63	111.21	188.10	103.03	584,725
1979	0.1464	0.1417	0.1809	0.5311	986,829	211.04	292.93	286.14	252.89	92.04	113.32	52.02	117.13	242.73	103.54	758,401
1980	0.1413	0.1540	0.1329	0.5718	1,150,515	244.03	370.50	308.25	307.92	89.59	113.56	41.37	120.75	229.89	105.47	731,665
1981	0.1487	0.1846	0.1235	0.5432	1,131,112	280.54	457.28	329.70	295.31	80.62	108.44	35.33	117.59	231.60	102.06	713,157
1982	0.1565	0.2077	0.1398	0.4960	1,065,790	297.22	512.09	357.59	256.75	75.48	102.64	34.75	116.36	241.10	98.93	719,537
1983	0.1456	0.2011	0.1436	0.5097	1,114,829	299.78	531.34	373.27	278.35	72.81	100.17	35.77	115.39	241.89	96.64	705,172
1984	0.1294	0.1830	0.1685	0.5191	1,178,802	304.22	518.93	394.39	294.27	67.42	98.69	42.00	117.53	258.16	96.79	753,802
1985	0.1274	0.1819	0.1776	0.5131	1,093,593	301.98	506.37	407.76	274.55	62.06	93.27	39.72	115.51	255.10	93.69	721,005
1986	0.1373	0.1862	0.2123	0.4642	1,030,237	298.88	474.06	418.15	240.05	63.65	96.09	43.61	112.60	294.16	92.17	817,921
1987	0.1379	0.1619	0.2319	0.4684	1,132,226	299.43	441.35	426.10	249.29	70.13	98.60	51.37	120.23	323.03	96.51	940,559
1988	0.1190	0.1268	0.2184	0.5358	1,378,342	301.62	415.69	442.82	313.23	73.14	99.84	56.69	133.26	306.11	102.08	942,713
1989	0.1388	0.1410	0.2006	0.5196	1,242,078	311.30	406.25	457.88	271.93	74.48	102.39	45.38	134.13	303.19	103.60	947,699
1990	0.1529	0.1520	0.2111	0.4841	1,181,701	326.29	405.67	462.06	238.74	74.45	105.11	45.03	135.42	298.41	103.08	927,818
1991	0.1484	0.1417	0.2280	0.4819	1,259,048	329.12	395.85	463.52	235.76	76.34	107.03	51.63	145.46	288.93	131.14	1,143,198
1992	0.1469	0.1360	0.2290	0.4881	1,315,124	326.62	384.79	516.17	241.94	79.52	110.37	48.66	149.96	285.04	117.82	1,013,198
1993	0.1560	0.1360	0.2213	0.4867	1,340,323	337.63	381.86	539.27	249.98	83.27	113.32	45.87	147.50	319.30	111.87	1,077,626
1994	0.1639	0.1402	0.1841	0.5118	1,384,761	358.46	395.82	567.66	268.06	85.13	116.48	37.45	149.43	311.64	120.15	1,129,664
1995	0.1510	0.1369	0.1544	0.5577	1,556,371	370.20	423.32	588.12	324.61	85.37	119.55	34.06	151.13	282.60	130.90	1,116,010
1996	0.1486	0.1522	0.1413	0.5579	1,539,251	382.81	450.84	602.64	321.72	80.35	123.42	30.09	150.87	267.20	119.75	964,936
1997	0.1439	0.1512	0.1682	0.5367	1,580,073	393.45	465.95	629.04	320.46	77.71	121.75	35.23	149.57	290.01	130.89	1,144,770
1998	0.1591	0.1614	0.1807	0.4988	1,519,843	396.19	481.88	633.79	294.35	82.09	120.85	36.13	145.57	282.00	132.58	1,127,928
1999	0.1706	0.1713	0.1824	0.4758	1,468,840	399.71	489.50	606.99	270.77	84.29	122.05	36.80	145.87	300.48	138.49	1,255,377
2000	0.1674	0.1661	0.1871	0.4794	1,563,721	435.78	493.64	640.35	282.14	80.78	124.90	38.10	150.18	338.54	151.80	1,550,412
2001	0.1532	0.1453	0.1587	0.5427	1,795,350	457.32	489.06	676.99	332.61	80.90	126.66	35.10	165.57	345.13	162.17	1,688,493
2002	0.1349	0.1319	0.1491	0.5841	1,975,994	449.78	493.92	689.02	381.96	79.68	125.33	35.66	170.78	297.74	180.54	1,621,637
2003	0.1420	0.1507	0.1466	0.5606	1,767,025	492.60	505.81	710.35	316.88	68.52	125.01	30.42	176.69	281.40	182.33	1,547,877
2004	0.1402	0.1547	0.1433	0.5618	1,752,083	493.98	518.09	746.44	299.14	66.88	124.21	28.05	185.99	264.11	191.92	1,528,952

Table B.5 Manitoba Crop Input/Output Data (1 of 2)

	Input Cost Shares				Total Cost	Input Price Indexes (1970=100)				Input Quantity Indexes (1970=100)				Crop Output Indexes		Total Revenue
Year	Capital	Land	Labour	Materials	('000 $)	Capital	Land	Labour	Materials	Capital	Land	Labour	Materials	Price	Quantity	('000 $)
1940	0.1452	0.1442	0.5432	0.1674	67,109	27.37	19.93	15.38	51.78	44.98	80.75	222.71	35.05	48.96	63.80	63,878
1941	0.1426	0.1291	0.5679	0.1604	75,110	29.10	20.18	18.59	54.88	46.51	79.93	215.67	35.45	53.59	66.50	72,615
1942	0.1324	0.1091	0.6038	0.1548	91,158	32.20	21.28	24.25	60.08	47.33	77.74	213.30	37.93	64.31	85.75	113,285
1943	0.1189	0.0933	0.6354	0.1523	111,051	34.76	22.44	29.91	71.14	48.00	76.85	221.72	38.41	93.21	70.73	135,488
1944	0.1112	0.0873	0.6505	0.1510	127,687	36.94	23.58	36.11	73.55	48.56	78.64	216.17	42.35	99.15	70.84	144,341
1945	0.1196	0.0912	0.6289	0.1603	132,063	38.07	24.72	37.25	77.77	52.40	81.08	209.55	43.96	109.52	62.05	139,661
1946	0.1189	0.0900	0.6324	0.1587	145,902	39.95	26.60	39.26	80.24	54.86	82.10	220.85	46.60	116.70	73.55	176,405
1947	0.1237	0.0920	0.6088	0.1755	157,318	43.90	28.78	41.52	89.19	56.01	83.62	216.77	50.01	140.77	63.41	181,249
1948	0.1382	0.0986	0.5959	0.1672	169,258	49.80	33.25	45.77	84.62	59.36	83.49	207.10	54.03	124.87	85.19	216,018
1949	0.1534	0.1011	0.5694	0.1762	184,045	53.71	36.35	49.11	89.89	66.41	85.10	200.55	58.26	138.09	66.88	197,659
1950	0.1785	0.1034	0.5482	0.1698	187,116	56.44	37.93	47.88	88.93	74.75	84.89	201.37	57.72	128.12	80.97	221,628
1951	0.1854	0.1050	0.5311	0.1785	202,582	62.74	39.86	53.82	90.45	75.64	88.77	187.85	64.57	128.48	81.93	224,797
1952	0.1838	0.1026	0.5399	0.1737	217,133	65.65	41.88	56.17	90.61	76.78	88.49	196.12	67.24	124.18	92.45	245,313
1953	0.2018	0.1124	0.5115	0.1743	211,017	64.35	44.62	57.84	86.10	83.60	88.47	175.38	68.98	102.86	81.69	179,406
1954	0.2165	0.1249	0.4769	0.1818	194,890	63.22	45.79	56.87	87.38	84.32	88.43	153.58	65.48	105.02	59.35	132,851
1955	0.2133	0.1211	0.4791	0.1865	196,341	62.97	44.78	54.77	88.25	84.01	88.31	161.43	67.02	110.28	69.62	163,702
1956	0.2014	0.1199	0.4993	0.1794	208,921	65.61	46.78	58.80	85.14	81.02	89.09	166.71	71.09	97.14	95.42	197,540
1957	0.2152	0.1274	0.4713	0.1861	200,153	68.31	48.25	62.20	85.75	79.65	87.95	142.53	70.16	97.51	70.77	147,269
1958	0.2110	0.1286	0.4759	0.1846	205,912	70.37	49.50	63.49	87.68	77.99	88.98	145.04	70.02	103.58	83.32	184,184
1959	0.2151	0.1292	0.4677	0.1881	212,406	73.43	51.04	65.11	89.13	78.60	89.43	143.39	72.39	107.62	82.79	190,164
1960	0.2163	0.1296	0.4628	0.1914	223,743	75.15	53.35	66.56	91.64	81.35	90.42	146.19	75.47	113.48	88.17	213,602
1961	0.2403	0.1466	0.3992	0.2139	207,100	76.47	56.30	67.21	95.42	82.21	89.71	115.60	75.00	128.59	45.81	125,613
1962	0.2184	0.1385	0.4420	0.2011	236,473	78.75	58.09	66.56	95.48	82.87	93.81	147.57	80.43	119.82	109.22	279,139
1963	0.2311	0.1468	0.4103	0.2118	236,960	79.72	60.80	67.37	95.40	86.78	95.18	135.62	84.97	119.23	90.10	228,877
1964	0.2264	0.1471	0.4103	0.2161	260,220	82.43	66.41	70.76	96.40	90.29	95.90	141.82	94.23	123.00	108.52	284,480
1965	0.2304	0.1570	0.3977	0.2149	276,248	83.98	74.43	74.80	97.43	95.76	96.92	138.02	98.43	124.30	115.87	306,860
1966	0.2246	0.1590	0.3799	0.2364	299,214	87.06	81.97	80.94	99.33	97.54	96.56	131.99	115.04	129.34	112.44	310,030
1967	0.2264	0.1658	0.3696	0.2382	315,810	89.83	90.53	85.95	100.41	100.57	96.21	127.62	121.02	121.92	113.68	295,616
1968	0.2283	0.1779	0.3476	0.2463	330,481	94.13	99.96	89.01	99.75	101.23	97.83	121.28	131.79	102.51	128.41	280,318
1969	0.2512	0.1953	0.3389	0.2147	309,256	97.08	102.55	93.54	100.42	101.07	97.96	105.29	106.81	97.57	113.96	236,351
1970	0.2574	0.1954	0.3459	0.2013	307,593	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	212,442
1971	0.2300	0.1622	0.3641	0.2436	339,849	101.86	97.85	105.49	101.40	96.96	93.73	110.24	131.89	97.19	152.23	316,363
1972	0.2261	0.1587	0.3528	0.2625	366,391	106.20	98.81	116.32	110.56	98.53	97.91	104.42	140.48	146.51	134.29	420,625
1973	0.2091	0.1440	0.3392	0.3077	449,269	111.71	107.84	131.34	139.43	106.23	99.83	109.02	160.15	291.38	143.50	894,954

Table B.5 Cont'd Manitoba Crop Input/Output Data (2 of 2)

	Input Cost Shares				Total Cost	Input Price Indexes (1970=100)				Input Quantity Indexes (1970=100)				Crop Output Indexes		Total Revenue
Year	Capital	Land	Labour	Materials	('000 $)	Capital	Land	Labour	Materials	Capital	Land	Labour	Materials	Price	Quantity	('000 $)
1974	0.2296	0.1538	0.2944	0.3221	516,626	128.30	128.52	153.47	165.52	116.80	102.86	93.14	162.40	289.51	110.38	682,688
1975	0.2411	0.1529	0.2818	0.3242	641,646	148.76	154.12	186.75	192.83	131.36	105.92	90.99	174.24	259.39	133.97	742,714
1976	0.2542	0.1589	0.2728	0.3141	727,799	161.00	180.01	221.00	206.29	145.18	106.87	84.41	178.99	228.04	147.08	718,603
1977	0.2392	0.1537	0.3104	0.2967	862,776	171.41	207.78	253.80	206.48	152.11	106.14	99.16	200.26	210.73	182.12	817,169
1978	0.2356	0.1594	0.2795	0.3255	990,147	185.77	244.08	268.82	221.20	158.66	107.59	96.74	235.31	240.31	202.44	1,034,908
1979	0.2338	0.1624	0.2553	0.3485	1,144,092	211.01	285.02	284.17	246.18	160.15	108.46	96.60	261.59	288.62	171.09	1,050,057
1980	0.2417	0.1704	0.2405	0.3474	1,272,861	243.93	334.61	297.58	292.12	159.35	107.82	96.68	244.47	345.38	140.43	1,032,385
1981	0.2399	0.1730	0.2256	0.3616	1,492,210	279.98	391.59	313.73	343.23	161.49	109.64	100.85	253.89	307.88	217.03	1,422,312
1982	0.2487	0.1719	0.2172	0.3622	1,577,792	296.81	414.21	330.69	349.37	167.03	108.95	97.38	264.17	269.33	235.01	1,349,128
1983	0.2470	0.1576	0.2178	0.3776	1,675,480	299.55	403.14	344.26	349.61	174.55	108.95	99.62	292.26	311.94	199.77	1,327,707
1984	0.2433	0.1532	0.2122	0.3913	1,739,916	304.18	398.15	356.06	361.76	175.78	111.35	97.46	304.01	311.68	233.25	1,548,292
1985	0.2349	0.1468	0.2216	0.3967	1,780,766	302.12	396.52	374.31	364.46	174.88	109.66	99.08	313.10	261.77	291.43	1,629,549
1986	0.2515	0.1489	0.2211	0.3785	1,687,072	299.92	391.34	388.69	339.50	178.72	106.82	90.17	303.79	208.64	263.68	1,172,301
1987	0.2573	0.1448	0.2198	0.3780	1,636,893	301.73	374.87	404.44	329.79	176.32	105.22	83.62	303.06	199.34	249.92	1,060,561
1988	0.2522	0.1430	0.2202	0.3846	1,678,550	304.47	357.61	426.79	331.16	175.65	111.66	81.38	314.88	306.09	162.63	1,060,066
1989	0.2477	0.1401	0.2364	0.3758	1,769,700	314.61	358.97	441.66	348.14	176.03	114.93	89.00	308.54	266.33	222.72	1,268,965
1990	0.2495	0.1419	0.2281	0.3806	1,762,602	329.35	386.13	445.26	355.73	168.66	107.72	84.85	304.59	202.55	304.79	1,320,473
1991	0.2474	0.1466	0.2233	0.3827	1,739,685	332.66	401.26	444.58	337.66	163.45	105.73	82.13	318.45	193.74	283.62	1,173,152
1992	0.2319	0.1363	0.2572	0.3746	1,877,274	330.63	406.32	527.95	346.19	166.33	104.79	85.94	328.09	210.25	318.06	1,436,651
1993	0.2296	0.1373	0.2535	0.3797	1,963,262	341.55	414.10	562.20	345.67	166.74	108.26	83.18	348.28	220.82	244.97	1,159,975
1994	0.2230	0.1325	0.2296	0.4149	2,121,928	362.10	427.04	550.57	377.97	165.08	109.49	83.17	376.23	261.91	311.37	1,752,032
1995	0.2274	0.1311	0.2108	0.4307	2,219,777	374.06	444.78	541.52	428.56	170.47	108.86	81.20	360.32	319.20	275.04	1,885,962
1996	0.2222	0.1293	0.2096	0.4389	2,375,832	386.77	470.69	581.58	443.20	172.45	108.60	80.45	380.00	287.50	328.03	2,025,130
1997	0.2232	0.1362	0.2036	0.4370	2,418,895	397.50	505.00	584.17	426.95	171.59	108.51	79.22	399.92	276.50	302.68	1,781,947
1998	0.2299	0.1420	0.1977	0.4304	2,443,742	399.44	532.84	604.01	405.94	177.69	108.36	75.15	418.50	255.40	348.72	1,894,970
1999	0.2502	0.1554	0.1708	0.4236	2,305,621	403.28	547.15	578.48	393.78	180.73	108.95	63.96	400.59	205.72	328.40	1,436,510
2000	0.2463	0.1569	0.1513	0.4455	2,326,634	438.57	554.72	610.27	417.22	165.08	109.48	54.21	401.25	211.08	361.98	1,624,400
2001	0.2468	0.1536	0.1355	0.4642	2,392,575	460.07	558.18	645.19	469.82	162.11	109.52	47.21	381.81	261.62	306.42	1,702,820
2002	0.2415	0.1489	0.1501	0.4595	2,490,034	453.20	568.47	656.65	443.69	167.59	108.47	53.50	416.56	287.06	334.27	2,038,130
2003	0.2361	0.1440	0.1437	0.4762	2,632,556	495.30	583.81	676.98	512.70	158.54	108.01	52.51	394.95	264.20	384.14	2,157,150
2004	0.2320	0.1445	0.1444	0.4791	2,682,274	496.88	601.14	711.37	494.22	158.19	107.27	51.18	419.96	264.20	347.59	2,001,326

Table B.6 Manitoba Livestock Input/Output Data (1 of 2)

	Input Cost Shares				Total Cost	Input Price Indexes (1970=100)				Input Quantity Indexes (1970=100)				Crop Output Indexes		Total Revenue
Year	Capital	Land	Labour	Materials	('000 $)	Capital	Land	Labour	Materials	Capital	Land	Labour	Materials	Price	Quantity	('000 $)
1940	0.0940	0.0519	0.4161	0.4379	64,853	28.73	22.22	15.38	41.18	79.15	85.61	188.46	52.60	32.99	72.27	51,774
1941	0.0772	0.0433	0.3843	0.4952	82,148	30.78	22.69	18.59	56.64	76.79	88.55	182.50	54.78	35.82	75.04	58,334
1942	0.0682	0.0377	0.3824	0.5118	101,546	35.78	24.13	24.25	63.32	72.16	89.49	172.03	62.60	45.75	85.99	85,376
1943	0.0628	0.0319	0.3225	0.5828	129,452	39.07	25.60	29.91	88.62	77.56	91.20	149.96	64.93	50.97	74.88	82,891
1944	0.0620	0.0316	0.3368	0.5696	144,324	39.97	27.00	36.11	96.38	83.42	95.49	144.62	65.06	49.24	80.44	86,030
1945	0.0666	0.0356	0.3508	0.5471	139,660	41.34	28.34	37.25	91.98	83.90	98.97	141.29	63.36	51.21	74.42	82,759
1946	0.0701	0.0411	0.3221	0.5667	137,048	44.10	30.90	39.26	102.76	81.29	102.93	120.78	57.64	56.24	67.86	82,894
1947	0.0665	0.0383	0.2911	0.6041	156,682	49.02	33.07	41.52	133.80	79.25	102.37	118.03	53.95	63.98	61.15	84,972
1948	0.0764	0.0440	0.3285	0.5511	157,958	57.54	38.24	45.77	121.43	78.21	102.73	121.80	54.67	80.72	63.06	110,570
1949	0.0756	0.0396	0.2991	0.5857	186,689	60.87	41.58	49.11	156.73	86.45	100.46	122.18	53.20	81.73	59.40	105,452
1950	0.0979	0.0456	0.3095	0.5470	164,522	63.07	42.80	47.88	135.60	95.23	99.09	114.26	50.62	81.84	61.57	109,495
1951	0.1004	0.0432	0.3324	0.5240	181,546	72.73	44.03	53.82	135.46	93.45	100.74	120.45	53.56	103.19	56.82	127,464
1952	0.1081	0.0432	0.2987	0.5500	178,472	69.84	46.28	56.17	132.11	103.03	94.16	101.96	56.66	81.26	62.59	110,543
1953	0.1117	0.0479	0.3648	0.4756	172,511	67.43	49.66	57.84	110.77	106.56	93.96	116.90	56.50	75.54	64.93	106,596
1954	0.0990	0.0439	0.3820	0.4751	184,715	66.42	50.07	56.87	114.88	102.67	91.57	133.30	58.26	75.02	64.95	105,901
1955	0.1005	0.0451	0.3330	0.5214	177,638	65.96	49.62	54.77	116.80	100.91	91.27	116.03	60.48	73.81	66.14	106,086
1956	0.1067	0.0500	0.3343	0.5090	166,889	67.41	51.97	58.80	101.72	98.53	90.72	101.92	63.70	71.08	69.45	107,282
1957	0.0987	0.0444	0.3886	0.4683	181,331	69.68	53.07	62.20	98.94	95.76	85.77	121.70	65.46	71.94	74.04	115,693
1958	0.0995	0.0446	0.3531	0.5028	186,043	73.06	54.91	63.49	103.89	94.44	85.38	111.17	68.68	79.27	74.66	128,599
1959	0.1058	0.0447	0.3401	0.5094	188,171	73.96	56.06	65.11	102.71	100.40	84.71	105.62	71.17	74.49	78.63	127,260
1960	0.1082	0.0451	0.3093	0.5374	190,671	75.13	58.92	66.56	108.19	102.43	82.50	95.18	72.23	74.38	77.37	125,046
1961	0.0866	0.0397	0.3340	0.5397	233,306	76.35	61.64	67.21	128.33	98.65	84.84	124.58	74.84	75.36	79.38	129,983
1962	0.1025	0.0502	0.2609	0.5864	196,509	80.01	63.25	66.56	119.76	93.83	88.15	82.75	73.39	81.97	79.86	142,264
1963	0.0959	0.0498	0.2704	0.5838	212,054	80.64	66.19	67.37	120.15	94.08	90.08	91.46	78.59	81.90	81.87	145,712
1964	0.0911	0.0508	0.2283	0.6298	229,789	81.25	71.86	70.76	127.25	96.03	91.83	79.65	86.75	78.61	87.79	149,964
1965	0.0897	0.0560	0.2347	0.6195	235,286	84.97	79.62	74.80	127.69	92.67	93.47	79.33	87.06	86.21	90.19	168,964
1966	0.0856	0.0571	0.2325	0.6249	254,023	89.09	86.56	80.94	135.44	91.00	94.58	78.39	89.39	92.28	88.48	177,434
1967	0.0966	0.0678	0.2606	0.5750	236,977	89.09	94.19	85.95	116.27	95.81	96.37	77.19	89.39	87.16	90.81	172,002
1968	0.1050	0.0787	0.2959	0.5204	223,807	92.20	101.54	89.01	103.77	95.09	97.97	79.93	85.60	88.11	93.40	178,834
1969	0.1053	0.0764	0.3530	0.4652	235,070	100.91	102.13	93.54	94.23	91.48	99.38	95.32	88.52	107.71	92.76	217,117
1970	0.0998	0.0659	0.3464	0.4879	268,713	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	217,322
1971	0.1098	0.0710	0.2922	0.5271	238,965	93.85	100.34	105.49	95.24	104.22	95.46	71.11	100.87	82.97	107.05	193,029
1972	0.0843	0.0590	0.2117	0.6451	322,078	106.66	103.51	116.32	150.59	94.88	103.72	62.97	105.23	106.26	103.49	238,971
1973	0.0547	0.0373	0.0953	0.8127	576,258	124.77	114.49	131.34	293.28	94.28	105.98	44.93	121.78	141.41	105.46	324,095

Table B.6 Cont'd Manitoba Livestock Input/Output Data (2 of 2)

Year	Input Cost Shares				Total Cost	Input Price Indexes (1970=100)				Input Quantity Indexes (1970=100)				Crop Output Indexes		Total Revenue
	Capital	Land	Labour	Materials	('000 $)	Capital	Land	Labour	Materials	Capital	Land	Labour	Materials	Price	Quantity	('000 $)
1974	0.0628	0.0463	0.1261	0.7648	589,729	139.55	135.09	153.47	271.63	99.02	114.17	52.04	126.64	153.59	110.14	367,595
1975	0.0696	0.0573	0.1373	0.7357	569,222	154.07	156.09	186.75	266.48	95.91	118.10	44.97	119.86	159.36	102.00	353,255
1976	0.0797	0.0705	0.1523	0.6975	525,720	157.26	180.07	221.00	237.43	99.33	116.21	38.93	117.79	147.60	98.99	317,446
1977	0.0867	0.0795	0.1980	0.6357	517,782	167.98	204.27	253.80	212.23	99.70	113.83	43.40	118.30	158.66	99.57	343,194
1978	0.0968	0.0889	0.1995	0.6148	534,415	191.35	235.62	268.82	213.90	100.83	113.88	42.60	117.16	198.61	102.09	440,581
1979	0.0925	0.0800	0.1891	0.6384	684,425	221.96	271.57	284.17	270.31	106.39	113.83	48.93	123.29	238.36	105.13	544,490
1980	0.0883	0.0745	0.1564	0.6808	840,810	234.09	312.68	297.58	349.83	118.28	113.18	47.48	124.79	220.78	107.27	514,514
1981	0.1015	0.0933	0.1579	0.6473	783,180	269.32	360.31	313.73	317.26	110.12	114.59	42.33	121.87	254.86	103.86	575,066
1982	0.1147	0.1083	0.1912	0.5858	699,614	282.12	376.48	330.69	256.75	106.07	113.70	43.45	121.74	262.25	105.20	599,309
1983	0.0983	0.0927	0.1779	0.6311	801,412	281.58	373.94	344.26	317.97	104.35	112.28	44.49	121.31	257.28	107.24	599,369
1984	0.0936	0.0917	0.1701	0.6446	821,645	292.38	368.36	356.06	324.37	98.09	115.59	42.16	124.53	276.60	112.52	676,138
1985	0.0971	0.0991	0.1885	0.6154	755,154	288.65	366.15	374.31	275.76	94.76	115.39	40.85	128.53	270.60	114.65	673,961
1986	0.1053	0.1035	0.2538	0.5373	719,088	297.31	366.42	388.69	231.15	95.01	114.79	50.44	127.49	295.05	114.59	734,412
1987	0.1110	0.1007	0.2670	0.5214	735,392	297.65	357.09	404.44	224.48	102.27	117.11	52.15	130.27	293.10	120.30	765,928
1988	0.0934	0.0796	0.2060	0.6210	938,158	287.09	345.91	426.79	333.65	113.80	121.96	48.65	133.18	263.70	123.51	707,498
1989	0.1056	0.0890	0.2150	0.5903	886,299	290.48	351.67	441.66	297.78	120.19	126.74	46.36	134.00	258.03	121.39	680,384
1990	0.1270	0.1050	0.2431	0.5250	790,539	308.82	375.14	445.26	235.40	121.19	124.97	46.37	134.47	281.34	121.73	743,922
1991	0.1201	0.1006	0.2468	0.5324	838,151	310.32	380.06	444.58	238.02	121.00	125.31	50.00	142.99	280.45	125.63	765,240
1992	0.1142	0.0974	0.2526	0.5358	895,825	305.24	384.23	527.95	251.09	124.95	128.25	46.06	145.80	271.61	129.45	763,611
1993	0.1116	0.0962	0.2972	0.4951	958,816	318.36	393.03	562.20	245.10	125.30	132.53	54.46	147.71	287.32	131.28	819,221
1994	0.1135	0.0975	0.2271	0.5618	1,000,313	332.53	404.30	550.57	277.78	127.37	136.22	44.34	154.32	293.69	138.44	883,085
1995	0.0932	0.0764	0.1685	0.6619	1,292,105	336.28	419.25	541.52	399.03	133.53	133.04	43.19	163.47	287.87	147.84	924,304
1996	0.0989	0.0853	0.2029	0.6129	1,228,909	356.36	441.38	581.58	329.89	127.15	134.16	46.06	174.15	316.93	154.54	1,063,713
1997	0.1034	0.0899	0.2253	0.5814	1,228,269	356.72	464.64	584.17	305.57	132.77	134.22	50.89	178.25	304.44	161.65	1,068,778
1998	0.1172	0.0971	0.2309	0.5548	1,165,236	343.21	483.44	604.01	272.98	148.38	132.17	47.86	180.62	274.72	178.42	1,064,495
1999	0.1219	0.0992	0.2365	0.5424	1,157,731	339.77	497.56	578.48	255.96	154.84	130.35	50.86	187.12	264.33	193.63	1,111,544
2000	0.1168	0.0953	0.2145	0.5734	1,267,258	383.94	498.56	610.27	286.48	143.75	136.80	47.85	193.46	315.22	210.82	1,443,233
2001	0.1118	0.0861	0.1824	0.6197	1,433,386	405.93	500.30	645.19	339.05	147.17	139.33	43.54	199.83	336.61	230.40	1,684,366
2002	0.1037	0.0810	0.1668	0.6486	1,554,480	377.93	510.27	656.65	379.80	158.99	139.31	42.43	202.46	292.52	240.59	1,528,483
2003	0.1074	0.0901	0.1786	0.6239	1,427,516	390.95	520.66	676.98	320.56	146.25	139.48	40.47	211.91	280.72	254.85	1,553,754
2004	0.0998	0.0876	0.1834	0.6293	1,491,338	378.01	548.92	711.37	320.76	146.76	134.38	41.31	223.15	256.20	280.06	1,562,514

APPENDIX C: ADDITIONAL EMPIRICAL RESULTS

Figure C.1 Prairie Crops: TFP, Terms of Trade, and Returns to Cost Indexes, 1940-2004

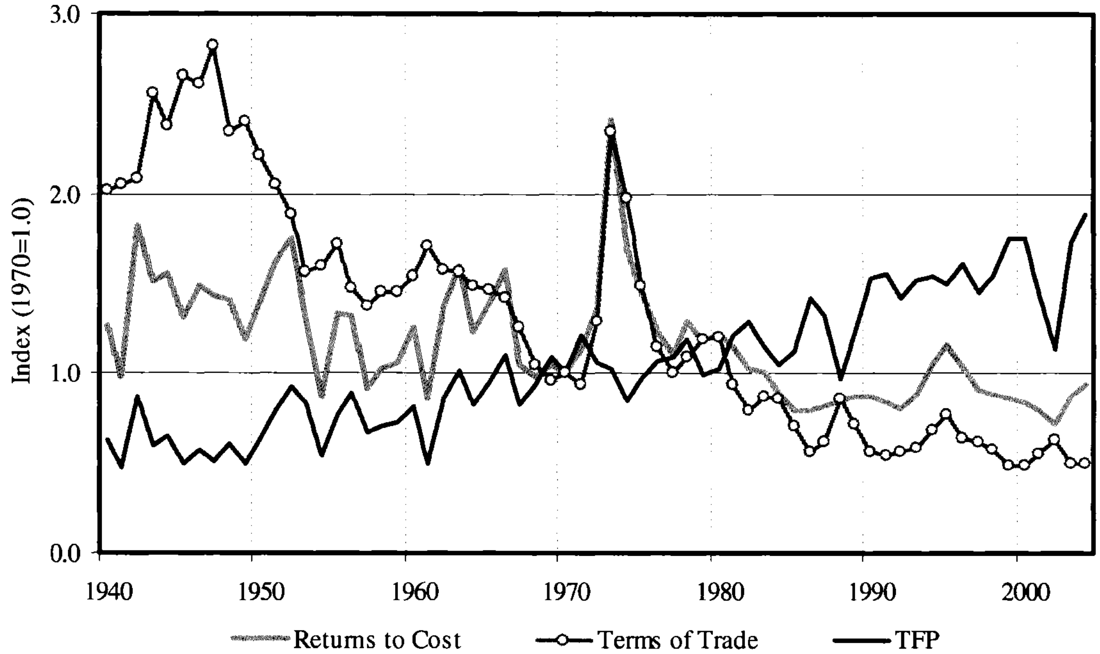


Figure C.2 Prairie Livestock: TFP, Terms of Trade, and Returns to Cost Indexes, 1940-2004

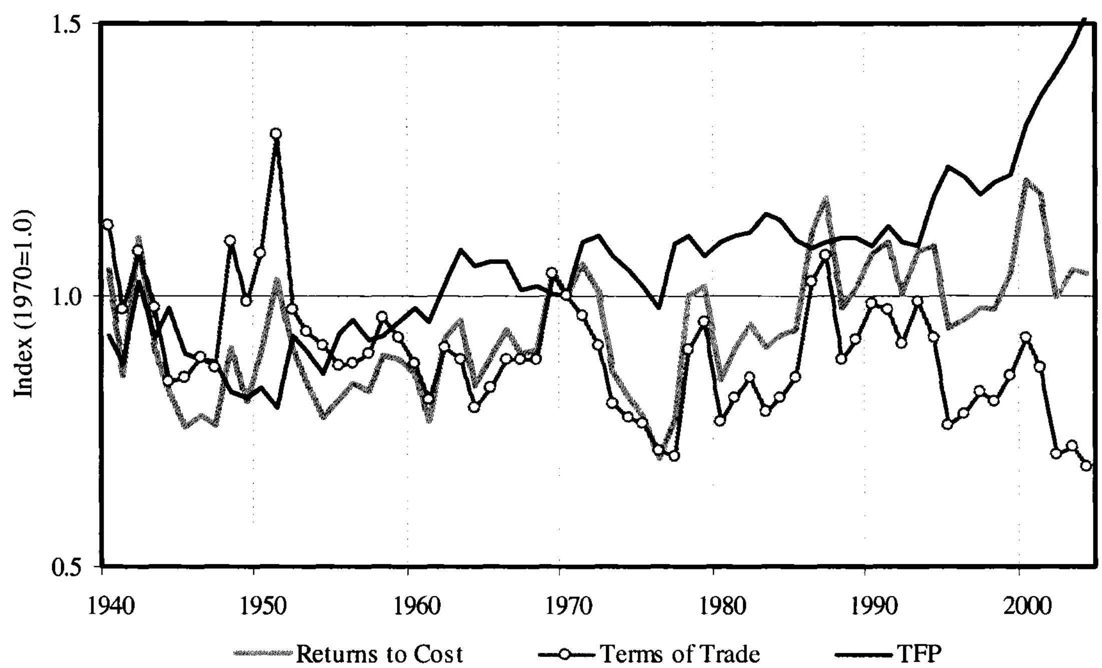


Figure C.3 Alberta Crops: TFP, Terms of Trade, and Returns to Cost Indexes, 1940-2004

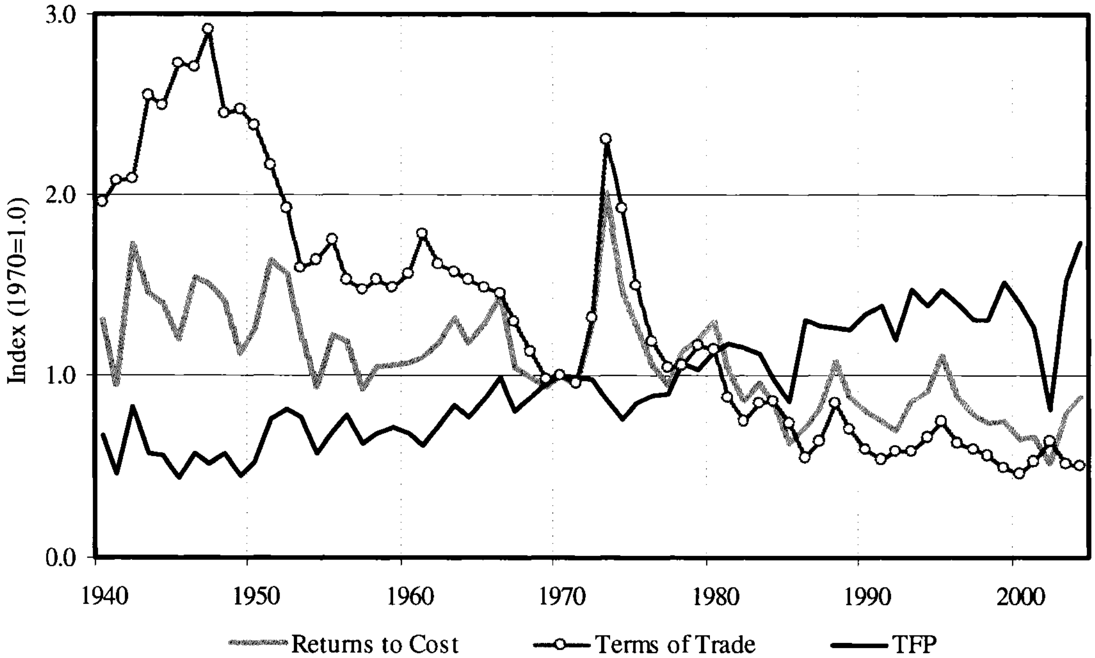


Figure C.4 Alberta Livestock: TFP, Terms of Trade, and Returns to Cost Indexes, 1940-2004

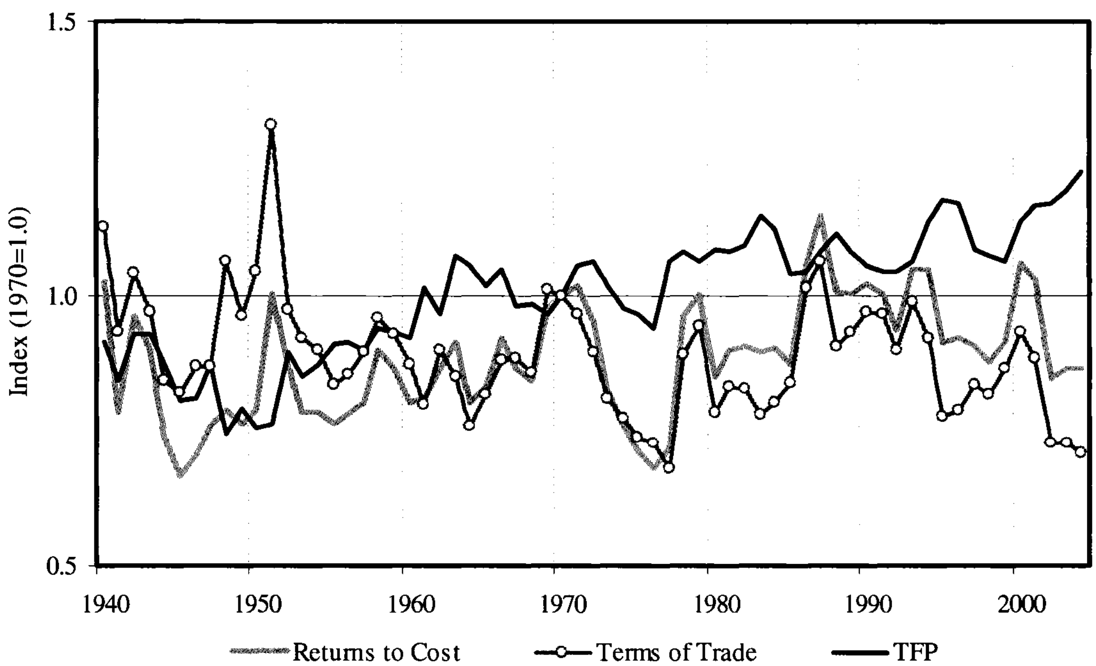


Figure C.5 Saskatchewan Crops: TFP, Terms of Trade, and Returns to Cost Indexes, 1940-2004

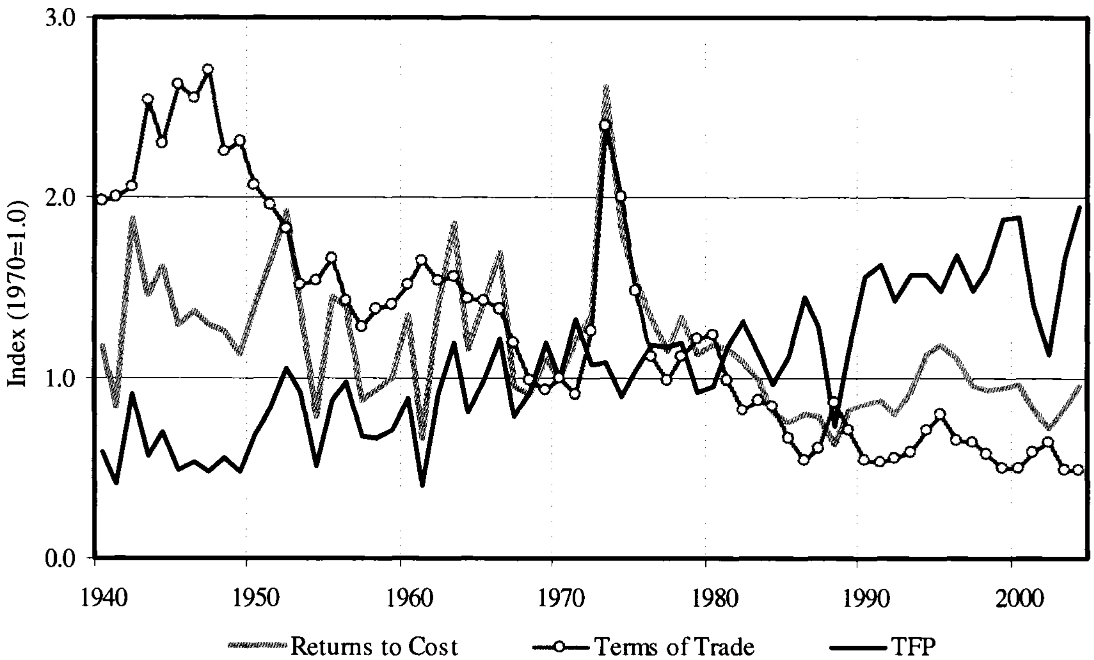


Figure C.6 Saskatchewan Livestock: TFP, Terms of Trade, and Returns to Cost Indexes, 1940-2004

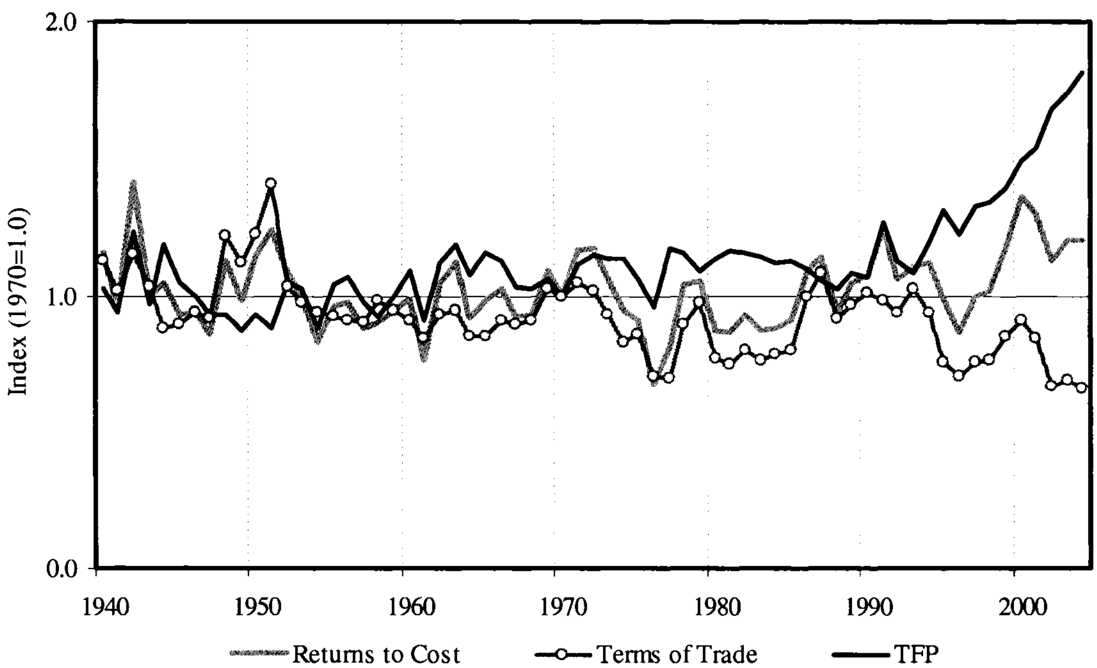


Figure C.7 Manitoba Crops: TFP, Terms of Trade, and Returns to Cost Indexes, 1940-2004

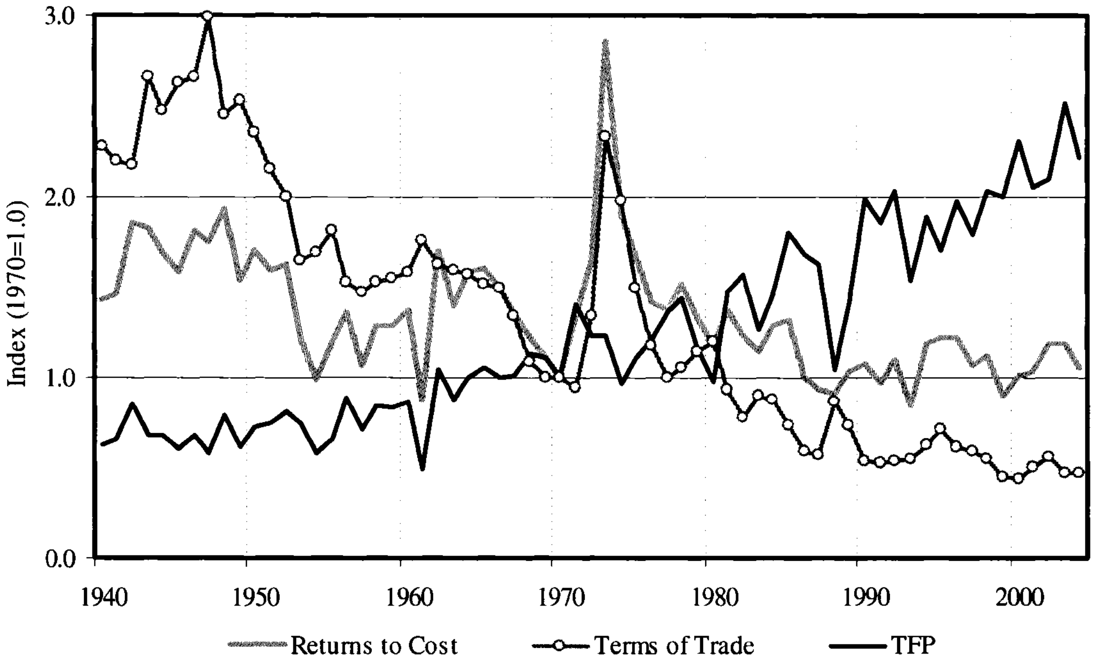
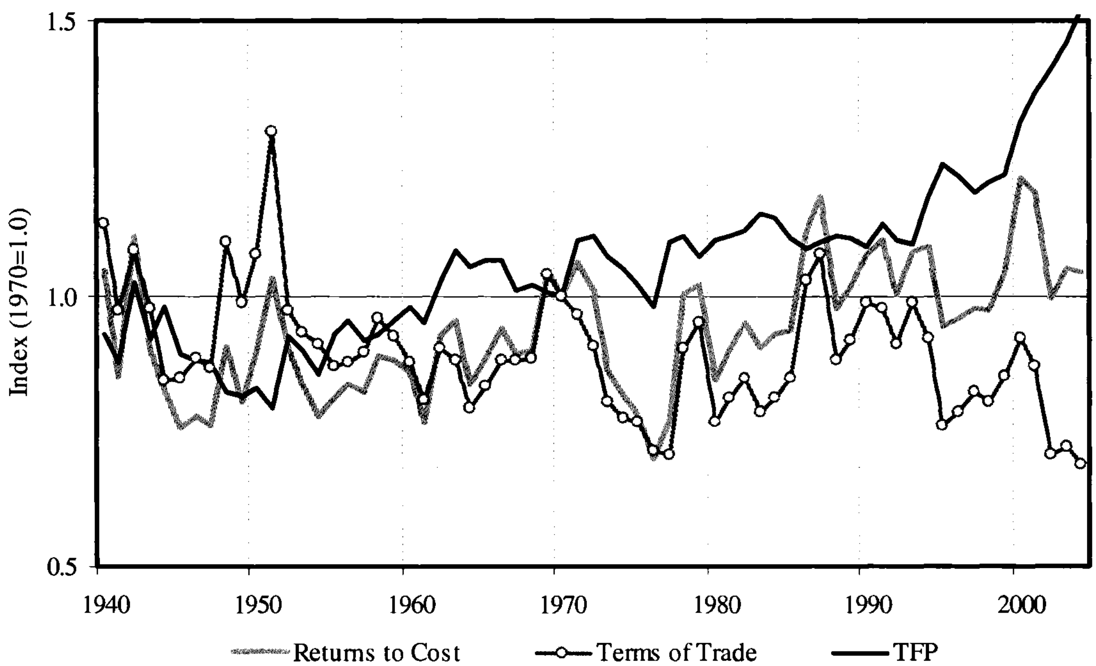


Figure C.8 Manitoba Livestock: TFP, Terms of Trade, and Returns to Cost Indexes, 1940-2004



APPENDIX D: TRANSLOG COST FUNCTION: ECONOMETRIC TESTING AND RESULTS

D.1 Coefficient Estimates and Econometric Test Statistics

Appendix D presents the coefficient estimates and summary econometric test statistics for the twelve translog cost functions estimated in the study. The results reported in Tables D.1 through D.8 relate to equations (6.1) through (6.6).

The coefficients estimates, reported in Tables D.1, D.3, D.5 and D.7, for all twelve cost functions perform well statistically: for Prairie agriculture - 86, 100, and 89 percent of the coefficients reported for the aggregate, crops, and livestock cost functions, respectively, are statistically significant at the one percent level; for Alberta agriculture - 81, 96, and 93 percent of the coefficients reported for the aggregate, crops, and livestock cost functions, respectively, are statistically significant at the one percent level; for Saskatchewan agriculture - 86, 82, and 86 percent of the coefficients reported for the aggregate, crops, and livestock cost functions, respectively, are statistically significant at the one percent level; and for Manitoba agriculture - 89, 86, and 93 percent of the coefficients reported for the aggregate, crops, and livestock cost functions, respectively, are statistically significant at the one percent level. The results suggest an appropriate functional form specification for each of the twelve cost functions.

Various econometric statistics are reported for the estimated Prairie and provincial cost functions. The R^2 measure reported in Tables D.2, D.4, D.6 and D.8 indicates that, in general, the cost functions and their related cost shares display suitable goodness of fit. The revenue cost share equations report substantially lower goodness of fit; however, this is anticipated since their sole role in the estimation is to ensure the imposition of the competitive behaviour assumption. Heteroskedasticity is detected in a few of the cost functions and their related cost and revenue shares. However, it does not appear that heteroskedasticity is pervasive: 33, 27, and 25 percent of the cost functions, cost shares, and revenue shares, respectively, display heteroskedasticity. Autocorrelation is more widespread. All cost functions, cost shares and revenue shares either exhibit autocorrelation or, in a smaller number of cases, the testing proved inconclusive. The errors for the systems of equations are largely normally distributed, and in the cases where they are not they may converge to normality asymptotically.

The identified autocorrelation could potentially be corrected by transforming the data or including lagged variables. The presence of heteroskedasticity and autocorrelation may, to some extent, reduce the efficiency of the estimates; nonetheless, the principal focus of the study is productivity growth and the overall return from the use of further measures to improve the estimates is anticipated to be low, relative to the time expended on their implementation.

Table D.1 Estimated Coefficients of Translog Cost Functions for Prairie Agriculture

Coefficients[a]	Aggregate Agriculture (Multi-Output Cost Function)	Crops Agriculture (Single-Output Cost Function)	Livestock Agriculture (Single-Output Cost Function)
α_0	15.6230**	15.2900**	14.4050**
α_1	0.2935**	1.0383**	
α_2	0.7923**		0.5645**
δ_{12}	-0.0811**		
δ_{11}	0.1798**	0.1972**	
δ_{22}	0.1763**		0.1389**
ϕ_t	-0.0140**	-0.0266**	-0.0163**
ϕ_{tt}	0.0001	0.0003**	0.0006**
δ_{1t}	0.0004	-0.0047**	
δ_{2t}	-0.0069**		-0.0084**
β_1	0.1136**	0.3044**	0.0427**
β_2	0.0739**	0.0842**	0.0858**
β_3	0.6014**	0.4973**	0.5146**
β_4	0.2112**	0.1141**	0.3569**
γ_{11}	0.1200**	0.2408**	0.2162**
γ_{22}	0.1063**	0.1578**	0.0871**
γ_{33}	0.1621**	0.1088**	0.2334**
γ_{44}	0.2118**	0.1385**	0.2819**
γ_{12}	0.0163**	0.0220**	-0.0662**
γ_{13}	0.0036	-0.0881**	-0.0655**
γ_{14}	-0.1399**	-0.1747**	-0.0845**
ρ_{11}	-0.0935**	0.0983**	
ρ_{12}	-0.0339**		-0.0558**
γ_{1t}	0.0020**	-0.0016**	0.0022**
γ_{23}	-0.1082**	-0.1184**	0.0043
γ_{24}	-0.0145**	-0.0614**	-0.0251**
ρ_{21}	-0.0334**	-0.0981**	
ρ_{22}	-0.0084*		-0.0233**
γ_{2t}	0.0017**	0.0023**	0.0002
γ_{34}	-0.0575**	0.0977**	-0.1722**
ρ_{31}	0.0075	-0.0399**	
ρ_{32}	0.0782**		-0.0433*
γ_{3t}	-0.0086**	-0.0047**	-0.0084**
ρ_{41}	0.1194**	0.0397**	
ρ_{42}	-0.0359**		0.1224**
γ_{4t}	0.0049**	0.0040**	0.0061**

** and * denote statistical significance at the one and five percent level respectively.

[a] See Section 6.1.2 and equations 6.1 and 6.4 for coefficient definitions for crops, livestock, and aggregate agriculture translog cost functions.

Table D.2 Prairie Econometric Test Statistics

		R^2	Breusch Pagan P-Value	Breusch Pagan Hetero-skedasticity	Durbin-Watson Statistic	Durbin-Watson Serial Correlation	Jarque-Bera Statistic	Jarque-Bera Normally Distributed Errors
Aggregate Agriculture (Multi-Output Cost Function)	Cost Function	0.9895	0.3418	No	1.6404	Inconclusive	1.1559	Yes
	Capital Share	0.9370	0.0129	Yes	0.7227	Yes	2.8403	Yes
	Land Share	0.9699	0.0038	Yes	0.6407	Yes	3.9299	Yes
	Labour Share	0.9674	0.0237	Yes	0.9317	Yes	5.5505	Yes
	Materials Share	0.9496	0.5194	No	1.1679	Yes	1.2273	Yes
	Livestock Revenue Cost Share	0.0293	0.7012	No	1.0656	Yes	6.3558	No
	Crops Revenue Cost Share	0.3160	0.0245	Yes	1.0267	Yes	5.5087	Yes
Crops (Single-Output Cost Function)	Cost Function	0.9845	0.6080	No	1.7914	Inconclusive	1.9975	Yes
	Capital Share	0.6714	0.8918	No	1.4395	Inconclusive	2.7364	Yes
	Land Share	0.8077	0.0025	Yes	1.4212	Inconclusive	5.1942	Yes
	Labour Share	0.9808	0.2970	No	1.3754	Yes	1.2852	Yes
	Materials Share	0.9088	0.9106	No	0.4359	Yes	3.1205	Yes
	Crops Revenue Cost Share	0.2200	0.3675	No	0.7592	Yes	17.0078	No
Livestock (Single-Output Cost Function)	Cost Function	0.9971	0.3991	No	0.7326	Inconclusive	1.0918	Yes
	Capital Share	0.6474	0.8389	No	0.5276	Yes	1.1559	Yes
	Land Share	0.9522	0.7977	No	0.5406	Yes	2.6624	Yes
	Labour Share	0.8076	0.0028	Yes	0.5557	Yes	7.0928	No
	Materials Share	0.7509	0.8178	No	0.5189	Yes	1.6546	Yes
	Livestock Revenue Cost Share	0.3266	0.8459	No	1.0703	Yes	0.9342	Yes

- In the estimation the materials cost share is dropped. To obtain R^2, Durbin-Watson and Jarques-Bera values for the materials cost share, it is added to the regression and the labour cost share is dropped. The Breush-Pagan test for heteroskedasticity is done separately for each equation.
- All estimates are made at the five percent level of significance.

Table D.3 Estimated Coefficients of Translog Cost Functions for Alberta Agriculture

Coefficients [a]	Aggregate Agriculture (Multi-Output Cost Function)	Crops Agriculture (Single-Output Cost Function)	Livestock Agriculture (Single-Output Cost Function)
α_0	14.8800**	14.3730**	13.5310**
α_1	0.3642**	1.1334**	
α_2	0.7900**		0.4253**
δ_{12}	-0.0163		
δ_{11}	0.1522**	0.3278**	
δ_{22}	0.2610**		-0.0056
ϕ_t	-0.0311**	-0.0359**	-0.0032**
ϕ_{tt}	0.0006**	0.0006**	0.0002**
δ_{1t}	0.0009	-0.0049**	
δ_{2t}	-0.0083**		0.0057**
β_1	0.1582**	0.2711**	0.0589**
β_2	0.0775**	0.1430**	0.0662**
β_3	0.4573**	0.5294**	0.4936**
β_4	0.3070**	0.0566**	0.3813**
γ_{11}	0.1906**	0.1204**	0.0731**
γ_{22}	0.1100**	0.1406**	0.0830**
γ_{33}	0.2904**	0.3195**	0.2645**
γ_{44}	0.1626**	0.1729**	0.3105**
γ_{12}	-0.0124*	-0.0303**	-0.0129**
γ_{13}	-0.1082**	-0.1038**	-0.0087
γ_{14}	-0.0700**	0.0137	-0.0516**
ρ_{11}	0.0036	0.1996**	
ρ_{12}	0.0804**		-0.0250**
γ_{1t}	0.0000	-0.0019**	0.0010**
γ_{23}	-0.0936**	-0.0698**	-0.0335**
γ_{24}	-0.0040	-0.0406**	-0.0366**
ρ_{21}	-0.0447**	-0.0455**	
ρ_{22}	-0.0042		-0.0478**
γ_{2t}	0.0017**	0.0007**	0.0010**
γ_{34}	-0.0885**	-0.1460**	-0.2223**
ρ_{31}	-0.0995**	-0.2000**	
ρ_{32}	-0.0448**		-0.0792**
γ_{3t}	-0.0047**	-0.0049**	-0.0078**
ρ_{41}	0.1406**	0.0459**	
ρ_{42}	-0.0313**		0.1520**
γ_{4t}	0.0030**	0.0061**	0.0057**

** and * denote statistical significance at the one and five percent level respectively.

[a] See Section 6.1.2 and equations 6.1 and 6.4 for coefficient definitions for crops, livestock, and aggregate agriculture translog cost functions.

Table D.4 Alberta Econometric Test Statistics

		R^2	Breusch Pagan P-Value	Breusch Pagan Hetero-skedasticity	Durbin-Watson Stat-istic	Durbin-Watson Serial Correlation	Jarque-Bera Stat-istic	Jarque-Bera Normally Distributed Errors
Aggregate Agriculture (Multi-Output Cost Function)	Cost Function	0.9923	0.0492	Yes	1.2283	Inconclusive	9.2572	No
	Capital Share	0.6600	0.9999	No	1.1131	Yes	6.4921	No
	Land Share	0.9674	0.3803	No	0.6463	Yes	1.6416	Yes
	Labour Share	0.9580	0.3942	No	0.5024	Yes	1.3664	Yes
	Materials Share	0.8865	0.1029	No	0.9901	Yes	3.2309	Yes
	Livestock Revenue Cost Share	0.0720	0.4553	No	0.8609	Yes	4.8072	Yes
	Crops Revenue Cost Share	0.4345	0.5963	No	0.7918	Yes	3.4220	Yes
Crops (Single-Output Cost Function)	Cost Function	0.9836	0.4871	No	1.4052	Inconclusive	4.2328	Yes
	Capital Share	0.9215	0.0373	Yes	1.4542	Inconclusive	2.3135	Yes
	Land Share	0.9686	0.0053	Yes	0.9312	Yes	0.8758	Yes
	Labour Share	0.8827	0.2424	No	1.2945	Yes	1.1421	Yes
	Materials Share	0.9290	0.4921	No	1.1025	Yes	2.2542	Yes
	Crops Revenue Cost Share	0.4163	0.2273	No	0.7728	Yes	6.5788	No
Livestock (Single-Output Cost Function)	Cost Function	0.9976	0.4037	No	0.6385	Yes	3.6841	Yes
	Capital Share	0.8553	0.4359	No	0.6395	Yes	2.0389	Yes
	Land Share	0.9386	0.9783	No	0.2990	Yes	12.4508	No
	Labour Share	0.8850	0.0428	Yes	0.9561	Yes	2.2493	Yes
	Materials Share	0.8223	0.5736	No	1.1950	Yes	2.3340	Yes
	Livestock Revenue Cost Share	0.1838	0.4080	No	0.8166	Yes	2.7868	Yes

- In the estimation the materials cost share is dropped. To obtain R^2, Durbin-Watson and Jarques-Bera values for the materials cost share, it is added to the regression and the labour cost share is dropped. The Breush-Pagan test for heteroskedasticity is done separately for each equation.
- All estimates are made at the five percent level of significance.

Table D.5 Estimated Coefficients of Translog Cost Functions for Saskatchewan Agriculture

Coefficients [a]	Aggregate Agriculture (Multi-Output Cost Function)	Crops Agriculture (Single-Output Cost Function)	Livestock Agriculture (Single-Output Cost Function)
α_0	14.6390**	14.1210**	13.2180**
α_1	0.2488**	0.5179**	
α_2	0.7444**		0.6669**
δ_{12}	-0.0460**		
δ_{11}	0.1643**	0.1698**	
δ_{22}	-0.0094		0.2029**
ϕ_t	-0.0077**	-0.0166**	-0.0109**
ϕ_{tt}	-0.0002*	0.0005**	0.0003**
δ_{1t}	-0.0004	-0.0083**	
δ_{2t}	-0.0016		-0.0070**
β_1	0.1170**	0.2064**	0.1037**
β_2	0.0858**	0.1360**	0.0769**
β_3	0.6564**	0.6460**	0.4733**
β_4	0.1408**	0.0117	0.3462**
γ_{11}	0.0665**	0.1123**	0.2170**
γ_{22}	0.1199**	0.1588**	0.0871**
γ_{33}	0.1528**	0.1054**	0.1495**
γ_{44}	0.2583**	0.2700**	0.2229**
γ_{12}	0.0248**	0.0527**	-0.0552**
γ_{13}	0.0314**	0.0105	-0.0503
γ_{14}	-0.1226**	-0.1754**	-0.1115**
ρ_{11}	-0.0604**	-0.0185**	
ρ_{12}	-0.0692**		-0.0894**
γ_{1t}	0.0016**	0.0002	0.0005
γ_{23}	-0.0966**	-0.1164**	-0.0098
γ_{24}	-0.0481**	-0.0950**	-0.0221**
ρ_{21}	-0.0309**	-0.0343**	
ρ_{22}	-0.0388**		-0.0278**
γ_{2t}	0.0019**	0.0012**	0.0009**
γ_{34}	-0.0876**	0.0005	-0.0893**
ρ_{31}	-0.0090	0.0443**	
ρ_{32}	0.0861**		0.0100
γ_{3t}	-0.0097**	-0.0083**	-0.0070**
ρ_{41}	0.1002**	0.0085	
ρ_{42}	0.0220**		0.1072**
γ_{4t}	0.0062**	0.0069**	0.0056**

** and * denote statistical significance at the one and five percent level respectively.

[a] See Section 6.1.2 and equations 6.1 and 6.4 for coefficient definitions for crops, livestock, and aggregate agriculture translog cost functions.

Table D.6 Saskatchewan Econometric Test Statistics

		R^2	Breusch Pagan P-Value	Breusch Pagan Hetero-skedasticity	Durbin-Watson Stat-istic	Durbin-Watson Serial Correlation	Jarque-Bera Stat-istic	Jarque-Bera Normally Distributed Errors
Aggregate Agriculture (Multi-Output Cost Function)	Cost Function	0.9673	0.9912	No	1.6521	Inconclusive	4.2328	Yes
	Capital Share	0.7239	0.2551	No	1.3848	Inconclusive	8.3781	No
	Land Share	0.9223	0.0161	Yes	1.2027	Yes	7.5704	No
	Labour Share	0.9573	0.8285	No	1.3969	Inconclusive	10.5520	No
	Materials Share	0.9735	0.4395	No	1.0977	Yes	2.3210	Yes
	Livestock Revenue Cost Share	**0.5448**	**0.0952**	**No**	**1.0031**	**Yes**	**8.2924**	**No**
	Crops Revenue Cost Share	**0.0158**	**0.0037**	**Yes**	**1.4106**	**Inconclusive**	**9.1657**	**No**
Crops (Single-Output Cost Function)	Cost Function	0.9926	0.2867	No	0.4820	Yes	6.8111	No
	Capital Share	0.8727	0.4898	No	0.2820	Yes	10.0951	No
	Land Share	0.8400	0.0205	Yes	0.2278	Yes	18.2230	No
	Labour Share	0.9924	0.3006	No	0.6894	Yes	4.0942	Yes
	Materials Share	0.8484	0.9242	No	0.2913	Yes	11.3352	No
	Crops Revenue Cost Share	**0.5344**	**0.1745**	**No**	**0.2795**	**Yes**	**23.8161**	**No**
Livestock (Single-Output Cost Function)	Cost Function	0.9941	0.0061	Yes	1.4508	Inconclusive	2.5003	Yes
	Capital Share	0.4115	0.4549	No	0.4390	Yes	3.8411	Yes
	Land Share	0.9395	0.0950	No	0.6475	Yes	2.8777	Yes
	Labour Share	0.7298	0.0034	Yes	0.8260	Yes	2.1330	Yes
	Materials Share	0.6714	0.0596	No	0.8398	Yes	3.9931	Yes
	Livestock Revenue Cost Share	**0.1758**	**0.7303**	**Yes**	**1.2932**	**Yes**	**3.6678**	**Yes**

- In the estimation the materials cost share is dropped. To obtain R^2, Durbin-Watson and Jarques-Bera values for the materials cost share, it is added to the regression and the labour cost share is dropped. The Breush-Pagan test for heteroskedasticity is done separately for each equation.
- All estimates are made at the five percent level of significance.

Table D.7 Estimated Coefficients of Translog Cost Functions for Manitoba Agriculture

Coefficients [a]	Aggregate Agriculture (Multi-Output Cost Function)	Crops Agriculture (Single-Output Cost Function)	Livestock Agriculture (Single-Output Cost Function)
α_0	14.0110**	13.6140**	12.9120**
α_1	0.2240**	0.9445**	
α_2	0.6590**		0.6013**
δ_{12}	-0.1517**		
δ_{11}	0.1436**	0.0169	
δ_{22}	0.2680**		0.2691**
ϕ_t	-0.0176**	-0.0322**	-0.0178**
ϕ_{tt}	0.0001**	0.0007**	0.0007**
δ_{1t}	0.0032**	-0.0107**	
δ_{2t}	-0.0043**		-0.0088**
β_1	0.0871**	0.1445**	0.0516**
β_2	0.0799**	0.0958**	0.0618**
β_3	0.5188**	0.7355**	0.5327**
β_4	0.3142**	0.0242	0.3539**
γ_{11}	0.1423**	0.0933**	0.1311**
γ_{22}	0.0910**	0.1306**	0.0508**
γ_{33}	0.1021**	0.1015**	0.2045**
γ_{44}	0.1696**	0.1774**	0.2790**
γ_{12}	-0.0285**	-0.0317**	-0.0489**
γ_{13}	-0.0278**	0.0203	-0.0213*
γ_{14}	-0.0860**	-0.0820**	-0.0609**
ρ_{11}	-0.0680**	-0.0286*	
ρ_{12}	0.0138*		-0.0201**
γ_{1t}	0.0017**	0.0017**	0.0009**
γ_{23}	-0.0266**	-0.0626**	0.0165**
γ_{24}	-0.0358**	-0.0363**	-0.0184**
ρ_{21}	-0.0227**	-0.0720**	
ρ_{22}	-0.0258**		-0.0163**
γ_{2t}	0.0009**	0.0017**	0.0001
γ_{34}	-0.0477*	-0.0591**	-0.1996**
ρ_{31}	0.0123	0.0601**	
ρ_{32}	-0.0425*		-0.0435**
γ_{3t}	-0.0059**	-0.0107**	-0.0088**
ρ_{41}	0.0783**	0.0406**	
ρ_{42}	0.0545**		0.0798**
γ_{4t}	0.0033**	0.0074**	0.0078**

** and * denote statistical significance at the one and five percent level respectively.

[a] See Section 6.1.2 and equations 6.1 and 6.4 for coefficient definitions for crops, livestock, and aggregate agriculture translog cost functions.

Table D.8 Manitoba Econometric Test Statistics

		R^2	Breusch Pagan P-Value	Breusch Pagan Hetero-skedasticity	Durbin-Watson Stat-istic	Durbin-Watson Serial Correlation	Jarque-Bera Stat-Istic	Jarque-Bera Normally Distributed Errors
Aggregate Agriculture (Multi-Output Cost Function)	Cost Function	0.9923	0.2557	No	1.8203	Inconclusive	6.9663	No
	Capital Share	0.8850	0.5589	No	0.4418	Yes	3.1178	Yes
	Land Share	0.9457	0.1701	No	1.3465	Yes	3.6305	Yes
	Labour Share	0.9095	0.4905	No	0.3450	Yes	22.2896	No
	Materials Share	0.8670	0.7795	No	0.5999	Yes	20.8850	No
	Livestock Revenue Cost Share	**0.7193**	**0.0587**	**No**	**1.3258**	**Yes**	**2.2267**	**Yes**
	Crops Revenue Cost Share	**0.3688**	**0.1370**	**No**	**0.7227**	**Yes**	**6.4819**	**No**
Crops (Single-Output Cost Function)	Cost Function	0.9920	0.0243	Yes	1.6261	Inconclusive	11.0261	No
	Capital Share	0.6788	0.4940	No	0.2106	Yes	7.5212	No
	Land Share	0.8275	0.0014	Yes	1.4616	Inconclusive	7.6702	No
	Labour Share	0.9658	0.4517	No	0.2164	Yes	7.5212	No
	Materials Share	0.9719	0.4362	No	1.2893	Yes	18.0564	No
	Crops Revenue Cost Share	**0.0301**	**0.1515**	**No**	**0.7845**	**Yes**	**6.5527**	**No**
Livestock (Single-Output Cost Function)	Cost Function	0.9880	0.0280	Yes	1.2572	Inconclusive	3.3628	Yes
	Capital Share	0.7600	0.3309	No	1.2143	Yes	1.7127	Yes
	Land Share	0.9234	0.1021	No	0.7590	Yes	0.3513	Yes
	Labour Share	0.7575	0.6544	No	0.4309	Yes	3.4805	Yes
	Materials Share	0.6266	0.0428	Yes	0.2257	Yes	4.1809	Yes
	Livestock Revenue Cost Share	**0.6643**	**0.3089**	**No**	**1.1405**	**Yes**	**5.9525**	**Yes**

- In the estimation the materials cost share is dropped. To obtain R^2, Durbin-Watson and Jarques-Bera values for the materials cost share, it is added to the regression and the labour cost share is dropped. The Breush-Pagan test for heteroskedasticity is done separately for each equation.
- All estimates are made at the five percent level of significance.

D.2 Maintained and Testable Hypotheses for Translog Cost Function

For the multi and single-output translog cost functions a number of maintained and testable hypotheses are required to render the results economically meaningful. The following two Sections will examine the maintained and testable hypotheseses of the twelve translog models used in the econometric analysis.

D.2.1 Maintained Hypotheses: Adding-Up, Symmetry and Homogeneity of Degree One in Input Prices

Linear homogeneity in input prices, adding-up and symmetry are the traditional maintained hypotheses employed when using the translog cost function. These maintained hypotheses, described in Section 6.1.2 and equation (6.7), are required in order to retain consistency with neoclassical economic theory. Nonetheless, the maintained hypotheses are not always consistent with the observed data; for example, Table D.9 indicates that the null hypothesis of linear homogeneity is rejected in a number of the cases. Nevertheless, the imposition of homogeneity (and adding-up and symmetry) is not unreasonable, since without the imposition of an appropriate degree of theoretical structure on the data, substantive insight into the production structure of agriculture and its implications for productivity growth is not possible.

Table D.9 Testing Homogeneity of Degree One in Input Prices

		P-Value (Wald Chi-Square Statistic)	Reject Homogeneity of Degree One in Input Prices
Prairie	Aggregate	0.0767	No
	Crops	0.3279	No
	Livestock	0.0290	Yes
Alberta	Aggregate	0.0061	Yes
	Crops	0.0034	Yes
	Livestock	0.0049	Yes
Saskatchewan	Aggregate	0.0125	Yes
	Crops	0.0323	Yes
	Livestock	0.5772	No
Manitoba	Aggregate	0.0049	Yes
	Crops	0.0011	Yes
	Livestock	0.3693	No

Rejection at five percent level of statistical significance.

D.2.2 Testable Hypotheses: Concavity in Input Prices and Monotonicity

Symmetry, adding-up and linear homogeneity in input prices are imposed *a priori.* For the cost function to be consistent with economic theory, the monotonicity and curvature conditions must also be checked. The monotonicity condition requires that the cost function be increasing in prices, and nondecreasing in output quantities (Antle and Capalbo, 1988). Antle and Capalbo show that the necessary and sufficient conditions for monotonicity in input prices and output can be written as follows:

Monotonicity in prices is verified by the cost shares being greater than zero:

$$\text{(D.1)}\quad S_r = \beta_r + \sum_{s=1}^{4} \gamma_{rs}(\ln W_s) + \sum_{i=1}^{2} \rho_{ir}(\ln Q_i) + \gamma_{rt}(T) > 0$$

Monotonicity in output is verified as follows:

$$\text{(D.2)}\quad \varepsilon_{CQ_i} = \frac{\partial \ln C}{\partial \ln Q_i} = \alpha_i + \delta_{ii}(\ln Q_i) + \sum_{i \neq j} \delta_{ij}(\ln Q_j) + \sum_{r=1}^{4} \rho_{ir}(\ln W_r) + \delta_{it}(T) > 0$$

Monotonicity in input prices and monotonicity in output are verified over the entire sample range, for each of the twelve cost functions. The translog cost function performs well in terms of the monotonicity conditions. However, satisfying the curvature conditions, i.e. the quasiconcavity of the cost function in input prices, is problematic.

A necessary condition for quasiconcavity of the cost function in input prices is the negativity of all own-price input elasticities which can be calculated following Binswanger (1974) as:

$$\text{(D.3)}\quad \sigma_{ii} = \frac{\gamma_{ii} + S_i^2}{S_i} - 1$$

Table D.10 lists the own-price elasticities for all twelve cost functions. It is evident that none of the twelve cost functions display negative own-price elasticities for each of their four respective inputs. Consequently, all twelve the cost functions violate the quasiconcavity in input prices property of a well-behaved cost function. In their analysis of Prairie agriculture for the 1948-1991 period, Veeman, Fantino, and Peng (1995) estimated a positive own price elasticity for land, suggesting that, at least for the land and building input, a positive own price elasticity may be a "reasonable" estimate for an input which has undergone periods of intense variability in price and speculative episodes.

However, positive and statistically significant own price elasticities for the other inputs is more difficult to explain.

Table D.10 Own-Price Input Elasticity Estimates - Calculated at Sample Means

		Capital	Land	Labour	Materials
Prairie	Aggregate	-0.1653**	-0.0652*	-0.1704**	-0.0565*
	Crops	0.2996**	0.1765**	-0.3386**	-0.2138*
	Livestock	0.8819**	0.0255	0.1435	0.0643
Alberta	Aggregate	0.4050**	-0.0680*	0.2412**	-0.1935**
	Crops	-0.1952*	0.0092	0.2505*	-0.0982*
	Livestock	-0.0656	-0.1392**	0.2201*	0.0880**
Saskatchewan	Aggregate	-0.4445**	-0.0363	-0.2097**	0.0976**
	Crops	-0.2185**	0.1396**	-0.3436**	0.2655**
	Livestock	0.7652**	-0.1157**	-0.1564	-0.0541
Manitoba	Aggregate	0.1356*	-0.0733**	-0.3609**	-0.1758**
	Crops	-0.3096**	0.0451	-0.3557**	-0.1090*
	Livestock	0.6115**	-0.1881**	0.0426	0.0617

** and * denote statistical significance at the one and five percent level respectively.

The problematic own-price input elasticity estimates raise a number of issues. Antle and Capalbo (1988) point out that the failure of the translog to satisfy curvature conditions, and hence obtain theoretically consistent elasticity measures, is widespread. This problem may be compounded by the relatively lengthy time period (sixty-five years) for which the translog cost function is expected to approximate the production process. Due to the limitations of the translog functional form it may be desirable to impose local curvature to obtain theoretically consistent estimates.[85] However, the own-price elasticity estimates are appreciably different from what theory dictates. This suggests that the

[85] For example, Hailu, Jeffrey, and Unterschultz (2005) successfully impose local concavity on a translog cost function altering the elasticities without substantively changing the results of their stochastic frontier cost efficiency analysis of dairy farms.

imposition of curvature might obfuscate underlying characteristics of the data. Due to time limitations these issues are left as open questions to be explored further in the future.

D.3 Model Summary

The cost functions estimated in this study do not perform perfectly; yet there is evidence that the results obtained are robust given the lengthy period of time covered by this study. The majority of the estimated coefficients are statistically significant; the goodness of fit is relatively good; and the empirical findings related to productivity growth are reasonable. It is anticipated that further refinements to the econometric models will yield diminishing returns, relative to the central objective of the study – the study of productivity growth in Prairie agriculture.

APPENDIX E: CAUSAL SUR MODEL: ECONOMETRIC TESTING

E.1 Econometric Performance of Causal SUR Model

Table 7.3 indicates that in terms of statistical significance the causal SUR model does not perform exceedingly well: only three of twelve coefficients for the crops equation, six of twelve for the livestock equation, and seven of seventeen for aggregate agriculture equation are statistically significant at the five percent level. Nevertheless, given the ad hoc nature of the modeling and data limitations the results are not unreasonable. Other econometric tests suggest that the model performs relatively well.

The Breusch-Pagan LM test rejects the null hypothesis of a diagonal covariance matrix, suggesting that an SUR estimation approach is appropriate with regard to contemporaneous correlation, in addition to its role in establishing the restrictions and relationships across the three equations. Table E.1 indicates the absence of heteroskedasticity and serial correlation in the model although the errors are not normally distributed. No R-squared goodness of fit measure is reported, since Wooldridge (2003) indicates that it is not applicable with first differenced data.

Table E.1 Causal SUR Econometric Test Statistics

	Breusch Pagan		Durbin-Watson		Jarque-Bera	
	P-Value	Hetero-skedasticity	Statistic	Serial Correlation	Statistic	Normally Distributed Errors
Aggregate TFP	0.1618	No	2.7749	No	27.0729	No
Crops TFP	0.7061	No	2.7790	No	38.5748	No
Livestock TFP	0.2198	No	2.6591	No	72.3173	No

• All null hypotheses are rejected at the five percent level of significance.

Overall the causal SUR model is somewhat limited econometrically. Further work to improve the estimation will likely involve: refinement of the data, testing a number of alternate lag structures for the independent variables, and dealing with potential endogenity, particularly with respect to structural change variables by employing three-stage least squares estimation.