Sources and Measurement of Agricultural Productivity and Efficiency in Canadian Provinces: Crops and Livestock

BY

Alexander B. Darku[1], Stavroula Malla[2] and Kien C. Tran[3]

[1 2 3] Department of Economics, University of Lethbridge, Alberta, Canada

December 13, 2012

CAIRN
AN ERCA RESEARCH NETWORK

Sources and Measurement of Agricultural Productivity and Efficiency in Canadian Provinces: Crops and Livestock

Alexander B. Darku [†]
Stavroula Malla [•]
and
Kien C. Tran [±]

Abstract

This study measures and assesses the variation in total factor productivity (TFP) growth among all the Canadian provinces in crops and livestock production over the period 1940-2009. It also determines if agricultural productivity growth in Canada has recently slowed down. The paper uses the stochastic frontier approach which incorporates inefficiency to decompose TFP growth into technical change, scale effect, and technical efficiency change. The results indicate that productivity changes were mainly driven by technical changes for crops, while the productivity change in livestock was mainly driven by scale effects. Technical progress contribution to productivity growth in livestock was also significant. Though change in technical efficiency is mainly positive (except for New Brunswick and Nova Scotia), its contribution to productivity growth was rather very little for the Provinces. We also found that, over the entire period, the productivity growth rates for the crop sub-sector are on average higher for the Prairie Provinces than for the Eastern and Atlantic Provinces. On the other hand, the productivity growth rates in the livestock sub-sector are on the average higher in Eastern and Atlantic Provinces than in the Prairie region with the exception of Manitoba. Finally, we found no evidence that agricultural productivity growth in Canada has recently slowed down. The decomposition of the TFP growth provides useful insights into the vital role of research and development (R&D) and in turn government support in agricultural sector productivity growth.

JEL Classification: Q1, Q10, Q13, Q22.

Keywords: Agricultural Productivity; Growth, Crops Farming, Livestock Farming, Total Factor Productivity, Technical Progress, Technical Efficiency, Scale Effect, Canada, Stochastic Production Frontier.

[† • ±] Department of Economics University of Lethbridge, Alberta, Canada

This research was financially supported by the CAIRN Research Network. An earlier version of this paper was presented at the 46th CEA Annual Meeting, Calgary, Alberta. We thank the participants of the session for valuable comments and suggestion. Also, we would like to thank Mike Tsionas for invaluable comments, suggestions and stimulating discussions. The usual disclaimer applies.

Introduction

This paper uses Canadian provincial data from 1940 to 2009 to measure and assess variation in total factor productivity (TFP) growth in the crops and livestock sub-sectors. The paper also investigates the pattern of agricultural productivity growth in Canada. The importance of such study, particularly for Canada, cannot be over emphasized. Agricultural productivity growth and efficiency in Canada has become a topic of continuing interest to policy makers and researchers who aim to improve on economic sustainability, efficiency, living standards, and international competitiveness. However, measuring agricultural productivity growth is a difficult task, but very important for various reasons. Firstly, agricultural productivity growth is an important indicator to the analysis of the overall economic growth. Secondly, expansion in the industrial sectors of all countries relies significantly on agricultural productivity growth even in today's world of synthetic substitutes for raw materials. Finally, it is an important concept in the discussions on global food security and poverty alleviation, especially in the developing world. Bruinsma (2009) stated that by 2050 the world population is expected to grow by 40% and allowing for increase in income and changes in diet, global demand for food and fiber is expected to grow by 70%. However, there are many different approaches to measuring agricultural productivity growth and their interpretation must be done carefully.

Recently, there has been debate on the direction of global agricultural productivity growth. Alston *et al* (2010a, b) used a range of partial productivity measures to examine productivity growth in the world. They found that with the exception of China and Latin America, there is evidence of an economically significant slow-down in agricultural productivity growth in most of the world since 1990. They concluded that in some part of the world the slow-down in agricultural productivity growth has been substantial and widespread. On the other hand Fuglie (2008, 2010) concluded differently when he examined long-run productivity trends in the global agriculture sector using an index number approach. He found that contrary to some other authors, there is no evidence of a general slow-down in sector-wide agricultural productivity, at least through 2007. He stated that the growth rate in agricultural Total Factor Productivity (TFP) has actually accelerated in recent decades because of rapid productivity gains in several developing countries, led by Brazil and China, and more recently to a recovery of agricultural growth in the countries of the former Soviet bloc.

In the case of Canada, recent evidence suggests that agricultural productivity growth has significantly slowed down as well as lagging behind that of the U.S. and many OECD countries (Rao *et al* 2008, Agriculture and Agri-Food Canada 2009). Moreover, Stewart *et al*, (2009) indicated that TFP growth rate for crops and livestock in the prairies has slowed down considerably. Veeman and Gray (2009) agreed with Stewart *et al*, 2009 by concluding that productivity growth in crop production has slowed down since 1990. On the contrary, the study by de Avillez (2011a, b) concluded that over the period 1961-2007, the primary agriculture sector in Canada experienced impressive productivity growth. . He also reported that the productivity growth performance in the agriculture sector by far exceeded productivity growth in the Canadian business sector as a whole.

The methodology and assumptions used in measuring agricultural productivity growth affect the magnitude of the estimates, as well as the direction of effects, as reflected in the studies discussed above and the general agricultural productivity literature. For example, most productivity measures have the underlying assumption that firms are efficient. If firms are actually inefficient, then the productivity measure could be misleading. Furthermore, the use of disaggregate data is very essential in measuring productivity growth, in order to reveal any possible idiosyncrasies of each provinces/regions and in turn appropriate policies to be implemented. Very few studies on Canadian agricultural productivity have used disaggregate data such as provincial data (e.g., Echevarria 1998, Steward 2006, Steward et al 2009). Furthermore, some Canadian studies have examined agricultural productivity growth while allowing for inefficiencies but for a specific crop or type of livestock farm within a specific province (Amara et al 1999, Giannakas et al 2000, Weersink et al 1990, Cloutier et al 1993).

The purpose of this paper is to use a stochastic frontier approach which incorporates inefficiency to decompose the TFP growth in Canadian agricultural sector into technical change, scale effect, and technical efficiency change[1]. We use provincial agriculture data (all provinces except Newfoundland) on Crops and Livestock sub-sectors for the period of 1940-2009. The paper also determines if agricultural productivity growth in Canada has slowed down as claimed by earlier studies. To the best of our knowledge, this is the first paper that examines TFP growth for all provinces in Canada for crops and livestock as well as decomposes TFP growth into technical change, scale effect, and technical efficiency change.

The rest of the paper is organized as follows. Section 2 provides a brief overview of mainly Canadian productivity and efficiency studies. Section 3 describes the theory behind the stochastic frontier approach used to decompose the TFP growth.

[1] We decomposed total factor productivity into three components: Technological progress; Scale effect; Technical efficiency. Technological progress captures the idea that production function can shift overtime. It refers to the situation in which a firm can achieve more output from a given combination of inputs or equivalently, the same amount of output from fewer inputs. Scale effect refers to the proportionate increase in output due to proportionate increase in all inputs in the production process.
Technical efficiency is the situation where it is impossible for a firm to produce with a given technology either (a) more output from the same inputs, or (b) the same output with less of one or more inputs without increasing the amount of other inputs. Hence, technical inefficiency indicates the amount by which actual output falls short of the max possible output.

Section 4 provides a brief description of the data used in the estimation. Details collections of the data are relegated to Appendix A. Section 5 describes the estimation procedure, while Section 6 provides the main estimation results. Concluding remarks are given in Section 7.

2. Productivity Growth and Efficiency Studies

There exists a large and growing literature on total factor productivity (TFP) growth in the Canadian agricultural sector, see for example, Fantino and Veeman (1997), Echervarria (1998), Steward (2006), Steward et al (2009), and Veeman and Gray (2009, 2010) for reference therein. However, with the exception of Echevarria (1998), Steward (2006) and Steward, Veeman and Unterschultz (2009), all of these studies used aggregate data. The main disadvantage of using aggregate data is that it does not allow for the identification of more productive provinces/regions versus less productive ones, and consequently, common policy may not be appropriate to promote productivity growth for all provinces/regions. However, finding agriculture data that is disaggregated enough, such as provincial or regions within each province, proves difficult due to the lack of available data. This is probably the main reason why previous studies have used aggregate data.

Echevarria (1998) managed to find provincial data on agriculture value added and three basic factors of production (capital, labor and land) for the period of 1971 to 1991, to examine TFP growth in the agriculture, services and industrial sectors. She used the standard Solow (1957) growth accounting technique along with constant return to scales Cobb-Douglas production function to compute the TFP growth across provinces. Her results indicated that Canadian agriculture is less labor intensive than both services and industry, while capital intensity is similar in the three sectors. In addition, the average TFP growth in the agriculture sector is approximately 0.3% which is similar to that of TFP growth in the Canadian industry.

Steward (2006) and Steward et al (2009) used Prairie region (Alberta, Saskatchewan and Manitoba) agriculture data on crop and livestock along with four factors of production (capital, labor, land and materials) for the period 1940 to 2004 to decompose the TFP growth into technological progress and scale effects. Their approach is based on Tornqvist-Theil indexing procedure coupled with econometric estimation of a Translog cost system. For the given period, they found that the productivity growth in the Prairie agriculture was at a rate of 1.56% per year, and that the productivity growth in crops is significantly higher than productivity in livestock. Furthermore, their results indicated that productivity growth in crops has largely been the result of technological progress while economies of scale have been the main source in generating productivity growth in livestock sector.

However, the main shortcoming of the above mentioned studies and many others is that the approaches used in computing TFP growth implicitly assumed that provinces/regions are fully efficiency in their production process (technically as well as allocatively). This may not be appropriate since at any given point in time, provinces/regions may not be fully efficient. Thus, by assuming provinces/regions are fully efficient in their production process when in fact they are not, the approach can provide misleading results and policy recommendations to enhance productivity growth. This shortcoming has been recognized in the literature. For instance, Tsionas and Kumbhakar (2004) pointed out that the approach or approaches that incorporate inefficiency is more attractive because it helps to identify which provinces/regions are inefficient and, if so, to what extent. By identifying the inefficient provinces/regions, policies designed to promote efficiency can be made more effective by directing the necessary aid to those who are in the greatest need of assistance.

Agricultural efficiency studies have mostly focused on agricultural practices in the Unites States and Europe. These studies have used diverse methodologies to identify the nature and the dynamics of efficiency in agriculture production. (see Barnes (2008), Zhu and Lansink (2010) Mayen et al, (2010) Serra et al (2008) and Guzman and Arcas (2008) for recent methodologies and results). A very notable study is the one by Bravo-Ureta et al (2007) which used meta-regression analysis of 167 frontier studies of technical efficiency in the agricultural sectors to determine the sensitivity of results to various methodologies. Though Canadian provincial studies are limited, a few notable ones are Amara et al, (1999) for Quebec potato farms; Giannakas et al (2000) for Saskatchewan wheat farms; Weersink et al (1990) for Ontario dairy farms; and Cloutier et al (1993) for Quebec dairy farms. The mean technical efficiency reported by the above Canadian studies range from 76.9 to 91.8, indicating that farms are not fully efficient and hence, there is a room for improvement in this front. While, the overall mean technical efficiency of all the 167 frontier studies included in Bravo-Ureta et al (2007) meta-regression analysis was 76.6.

3. Methodology

The method used in this paper is based on stochastic production frontier approach originally proposed by Lovell and Schmidt (1977), and Meeusen and van den Broeck (1977). A specification of a stochastic production frontier function can be generally written as:

$$Y_{it} = f(X_{it}, t; \boldsymbol{\beta}) \exp(v_{it} - u_{it}) \tag{1}$$

where Y_{it} denotes the output of province i at time t , X_{it} is a $k \times 1$ vector of input factors used in the production process, t is a time trend which capture the technical change, $\boldsymbol{\beta}$ is a $k \times 1$ vector of unknown parameters to be estimated, v_{it} is an *i.i.d.* symmetric random disturbance such that $v_{it} \sim N(0, \sigma_v^2)$, $u_{it} \geq 0$ is an *i.i.d.* nonnegative random variable representing technical inefficiency and the function $f(.,.)$ is the production technology and we assume it takes a specific form. The idea behind model (1) is that for a given technology and at any point in time, provinces are not always fully efficient in implementing the best possible practice from the present stock of knowledge. Following the stochastic frontier literature, it is assumed that $u_{it} \sim \left| N(0, \sigma_u^2) \right|$, albeit other nonnegative distributions such as exponential, gamma, etc. could be considered. However, it is known that the estimation results are not sensitive to the distributional assumption on u_{it} (see Greene (2002).)

Let $y_{it} = \ln Y_{it}$ and similarly $x_{it} = \ln X_{it}$. Following Kumbhakar and Lovell (2000), in the primal approach, when price information is available, TFP changes can be decomposed into four components: technical change (TC), scale effect (SE), technical efficiency change (TEC) and changes in allocative inefficiency (AEC). To do this, let $\dot{z}$ denotes the growth rate of a variable Z, that is, $\dot{z} = \partial \ln Z / \partial t$; and define TFP growth as output growth unexplained by input growth. That is,

$$T\dot{F}P = \dot{y} - \sum_{j=1}^{k} s_j \dot{x}_j \tag{2}$$

where s_j is the j^{th} input share of production cost and $\dot{x}_j = \partial \ln X_j / \partial t$. The output growth $\dot{y}$ can be computed based on Farrel's definition of technical efficiency:

$$TE = \frac{Y}{f(X,t;\beta)} \tag{3}$$

By taking natural logarithm of (3) and total differentiate with respect to time, we obtain:

$$\frac{d\ln TE}{dt} = \frac{d\ln Y}{dt} - \sum_{j=1}^{k} \frac{\partial \ln f(X,t;\beta)}{\partial X_j} \frac{dX_j}{dt} - \frac{\partial \ln f(X,t;\beta)}{\partial t}$$

which can be rewritten as

$$\frac{d\ln Y}{dt} = \frac{\partial \ln f(X,t;\beta)}{\partial t} + \sum_{j=1}^{k} \left\{ \frac{\partial \ln f(X,t;\beta)}{\partial X_j} \frac{1}{X_j} \frac{dX_j}{dt} + \frac{d\ln TE}{dt} \right\}$$

or equivalently

$$\dot{y} = TC + \sum_{j=1}^{k} \varepsilon_j \dot{x}_j + T\dot{E} \tag{4}$$

where ε_j is the output elasticity with respect to input j. Replacing $\dot{y}$ in (2) with (4), the TFP growth can be written as:

$$T\dot{F}P = TC + \sum_{j=1}^{k} (\varepsilon_j - s_j)\dot{x}_j + T\dot{E} \tag{5}$$

For convenient, (5) can be expressed in term of scale of production $\varepsilon = \sum_j \varepsilon_j$ by adding and subtracting $\varepsilon_j / \varepsilon$ in the parenthesis of the second term on the right hand side of (5) yielding the TFP growth decomposition:

$$T\dot{F}P = TC + (\varepsilon - 1)\sum_{j=1}^{k} \left(\frac{\varepsilon_j}{\varepsilon} \right) \dot{x}_j + T\dot{E} + \sum_{j=1}^{k} \left(\frac{\varepsilon_j}{\varepsilon} - s_j \right) \dot{x}_j \tag{6}$$

The first term on the right hand side of (6) measures the TC which relates to the technological progress including not only advances in physical technologies but also innovation in the overall knowledge base that lead to better decision making and planning. It captures the upward shift of the production function. The second term on the right hand side of (6) measures the SE which refers to the proportionate increase in output due to proportionate increase in all inputs in the production process. Note that in the presence of constant returns to scale, $\varepsilon = 1$, this term vanishes. The third term on the right hand side of (6) measures the changes in TEC and the last term measures AEC which refers to the deviation of each input value of marginal productivity from output normalized cost. The AEC will vanish if the provinces/regions/farms are allocatively efficient. However, in the present study, we do not make adjustment for the AEC since input prices data are incomplete. We hope to address the AEC in the near future.

The data used in this paper comes from various Statistics Canada publications and Census of Agriculture years. We used nine provinces in this study. Newfoundland, the Yukon and the Northwest Territories are excluded because they are practically deserted and few statistics available from them. The period chosen in this study is from 1940 to 2009. The length of this data series is unusual since few studies of Canadian agricultural productivity have access to approximately 70 years of data. This enables us to make assessment of various provincial agriculture growths and productivity performance both for relatively long period of time and for different time periods.

Most of the data was retrieved from CANSIM and in some situation multiple tables had to be combined in order to cover the time period of interest, as some tables had been terminated. The census data, which was required for input allocation, was retrieved partially from CANSIM, namely data from the Census years 2001 and 2006. Data from the census years 1941 to 1996 was retrieved from printed Census of Agriculture documents found in the University Library. Census data is available online through CANSIM for the census years between 1991 and 2006, with select historical data being available prior to these years.

For agriculture sector, the outputs considered in this paper are the aggregate crop and livestock outputs measured in real terms using Farm Product Price Index (1997 = 100). Inputs are aggregate into the four main input categories: capital (K), including machinery and equipment, and livestock inventory; labor (L) including paid and unpaid labor; land and buildings (LB), including cropped land, pasture, summer fallow and buildings; and materials (M), including fertilizer, seed, pesticides, feed, fuel, electricity, irrigation and other miscellaneous expenses. Inputs are not adjusted for changes in quality overtime. A comprehensive description and the methodologies use in the construction of the outputs and the inputs data for crop and livestock are given in Appendix A. Table 1 and 2 below provide the summary statistics for the variables (expressed in natural logarithm) used in the estimation.

Table 1: Summary Statistics for Crop Data: 1940 - 2009

	OUTPUT	CAPITAL	LAND	LABOR	MATERIAL
			Alberta (AB)		
mean	14.51	14.65	15.84	12.34	14.07
std	0.55	0.73	0.80	0.57	0.72
max	15.49	15.59	17.26	13.57	16.44
min	13.42	13.61	14.71	11.26	12.92
			British Columbia (BC)		
mean	12.01	12.19	14.34	12.93	12.08
std	0.55	0.90	1.07	0.31	0.51
max	13.02	13.33	16.31	13.58	13.14
min	10.77	10.54	12.82	12.34	11.27

			Manitoba (MAN)		
Mean	13.93	13.95	15.19	12.55	13.63
std	0.54	0.74	0.58	0.41	0.65
Max	14.89	14.79	16.31	13.41	15.46
Min	11.94	12.63	14.31	11.49	12.41
			New Brunswick (NB)		
Mean	11.47	11.20	12.17	10.59	11.12
std	0.23	0.61	0.67	0.39	0.98
Max	11.95	12.08	13.67	11.47	14.06
Min	10.79	10.17	11.36	9.80	9.71
			Nova Scotia (NS)		
Mean	10.72	10.55	11.98	10.34	10.30
std	0.26	0.49	0.86	0.57	0.71
Max	11.36	11.30	13.62	11.40	12.01
Min	10.10	9.50	10.56	9.29	9.04
			Ontario (ON)		
Mean	14.26	14.11	15.90	13.58	14.04
std	0.50	0.76	0.91	0.29	0.50
Max	15.14	14.95	17.51	14.20	15.47
Min	13.12	12.80	14.70	12.96	13.28
			Prince Edward Island (PEI)		
Mean	11.58	10.87	11.78	9.94	11.07
std	0.46	1.10	1.28	0.89	0.95
Max	12.41	12.20	13.67	11.31	13.01
Min	10.75	8.96	10.23	8.11	9.42
			Quebec (QC)		
Mean	13.39	12.60	13.72	12.21	12.80
std	0.48	0.97	1.22	0.31	0.56
Max	14.31	13.90	16.07	12.68	13.75
Min	12.35	11.46	12.26	11.62	11.81
			Saskatchewan (SK)		
Mean	14.87	15.22	16.41	13.31	18.46
Std	0.53	0.65	0.59	0.71	1.65
Max	15.94	16.07	17.58	15.34	20.81
Min	13.76	14.16	15.61	11.46	16.33
			Canada		
Mean	15.95	16.33	17.59	15.61	16.56
Std	0.49	0.53	0.61	0.62	0.93
Max	16.83	16.86	18.87	16.74	18.21

Min	15.06	15.11	16.81	14.27	15.16

All variables are measured in natural logarithm.

Table 2. Summary Statistics for Livestock Data: 1940 – 2009

	OUTPUT	CAPITA	LAND	LABOR	MATERIAL
			Alberta (AB)		
mean	14.42	14.62	16.17	12.80	13.96
std	0.60	0.73	0.93	0.61	0.67
max	15.36	15.38	17.84	13.84	15.56
min	13.39	12.88	14.32	11.49	13.14
			British Columbia (BC)		
mean	13.26	12.91	15.04	13.30	13.21
std	0.48	0.87	0.94	0.43	0.46
max	13.94	13.96	16.75	14.04	14.50
min	12.26	11.42	13.54	12.11	12.63
			Manitoba (MAN)		
Mean	13.60	13.05	14.70	12.05	13.20
std	0.46	0.99	0.65	0.50	0.73
Max	14.47	14.09	15.87	13.07	14.88
Min	12.85	11.28	13.74	10.70	12.25
			New Brunswick (NB)		
Mean	11.83	11.57	12.67	10.69	11.81
std	0.24	0.54	0.60	0.49	0.90
Max	12.25	12.35	13.86	11.50	14.00
Min	11.52	10.83	11.78	9.48	10.72
			Nova Scotia (NS)		
Mean	12.14	12.18	13.11	10.90	12.08
std	0.29	0.34	0.50	0.35	0.63
Max	12.55	12.65	13.98	11.57	13.97
Min	11.50	11.67	12.41	10.09	11.42
			Ontario (ON)		
Mean	14.96	14.96	16.80	13.59	14.83
std	0.24	0.29	0.61	0.30	0.72
Max	15.27	15.39	17.93	14.30	16.84
Min	14.44	14.44	15.82	13.11	14.05
			Prince Edward Island (PEI)		

Mean	11.43	11.19	12.15	9.74	11.25
std	0.21	0.64	0.85	0.75	0.85
Max	11.75	11.93	13.24	10.87	13.63
Min	11.00	10.05	11.01	7.91	10.41
Quebec (QC)					
Mean	14.64	14.36	15.34	13.31	14.53
std	0.37	0.52	0.83	0.36	0.62
Max	15.17	15.00	17.01	13.92	15.90
Min	13.91	13.40	14.26	12.60	13.59
Saskatchewan (SK)					
Mean	13.68	13.71	14.93	12.34	17.66
Std	0.37	0.54	0.59	0.62	1.50
Max	14.44	14.29	15.81	13.90	19.59
Min	12.95	12.06	13.39	10.90	15.34
Canada					
Mean	16.13	17.37	17.06	15.61	15.72
Std	0.38	0.47	1.47	0.56	0.57
Max	16.71	18.63	18.72	16.60	17.13
Min	15.42	16.88	11.21	14.38	15.04

All variables are measured in natural logarithm.

5. Estimation Procedure

For the estimation purpose, we need to specify a functional form for the production function $f(.)$. In this paper; we use the flexible Translog form:

$$y_{it} = \beta_o + \sum_{j=1}^{4} \beta_j x_{jit} + \gamma_1 t + \frac{1}{2}\gamma_2 t^2 + \sum_{m=1}^{8} \delta_m D_{mit} + \frac{1}{2}\sum_{j=1}^{4}\sum_{l=1}^{4} \beta_{jl} x_{jit} x_{lit} + \sum_{j=1}^{4} \beta_{tj} t x_{jit} + \sum_{m=1}^{8} \delta_{mt} t D_{mit} + v_{it} - u_{it} \quad (7)$$

where D_{it} represent the provincial dummy. The specification in (7) is quite comprehensive and it allows for general form of non-neutral technical change. In addition, it contains the Cobb-Douglas production with neutral technical change as a special case when $\beta_{jl} = \beta_{tj} = \gamma_2 = 0$ for all j and l.

Estimation of (7) is carried out using ML method. To write down the log-likelihood function, let $e_{it} = v_{it} - u_{it} = y_{it} - \ln f(X_{it}, t; \beta)$. Under the distributional assumptions of v_{it} v_{it} and u_{it} u_{it}, the conditional probability density function of ε_{it} e_{it} is given by

$$f(e_{it} \mid x_{it}) = \frac{2}{\sigma}\phi\left(\frac{e_{it}}{\sigma}\right)\Phi\left(-\frac{\lambda e_{it}}{\sigma}\right), \qquad -\infty < e_{it} < +\infty$$

where $\sigma^2 = \sigma_v^2 + \sigma_u^2$, $\lambda = \sigma_u / \sigma_v$, $\phi(.)$ and $\Phi(.)$ are the probability density function (pdf) and cumulative distribution function (CDF) of a standard normal variable. In order to avoid non-negativity restrictions on the variance parameters σ^2 and λ, we choose to re-parameterize these parameters as $\tilde{\sigma}^2 = \ln(\sigma^2)$ and $\tilde{\lambda} = \ln(\lambda)$.

The conditional log-likelihood function for a sample of NT observations is given by:

$$\ln L(\theta) = -\frac{NT}{2}(\ln 2\pi + \ln \tilde{\sigma}^2) - \frac{1}{2}\sum_{i=1}^{n}\sum_{t=1}^{T}\{[y_{it} - \ln f(X_{it}, t; \beta)] / \tilde{\sigma}^2\} + \sum_{i=1}^{n}\sum_{t=1}^{T}\ln\Phi\{-\frac{\tilde{\lambda}}{\tilde{\sigma}}[y_{it} - f(X_{it}, t; \beta)]\} \qquad (8)$$

where $\theta = (\beta, \tilde{\sigma}^2, \tilde{\lambda})$. By maximizing (8) with respect to θ, the ML estimates of θ can be written as:

$$\hat{\theta} = \arg\max_{\theta \in \Theta} \ln L(\theta) \qquad (9)$$

Note that the log-likelihood function in (8) is highly non-linear and it requires some types of numerical algorithm and stating values in the optimization process. In this paper, we use the corrected OLS (see for example, Kumbhakar and Lovell (2000)) estimates of (9) as the starting values in the optimization process along with

David-Fletcher algorithm. The convergence criterion is set at 10^{-5}. In our estimation, we did not encounter any numerical problems and the parameter estimates converged quickly.

Once the parameter estimates are obtained, the technical inefficiency term u_{it} can be predicted via Jondrow et al. (1982) prediction formula:

$$\hat{u}_{it} = E(u_{it} \mid e_{it}) = \frac{\hat{\sigma}\hat{\lambda}}{1+\hat{\lambda}^2}\left\{\frac{\phi(\hat{\lambda}\hat{e}_{it} / \hat{\sigma})}{\Phi(\hat{\lambda}\hat{e}_{it} / \hat{\sigma})} - \frac{\hat{\lambda}\hat{e}_{it}}{\hat{\sigma}}\right\} \quad (10)$$

where $\hat{e}_{it}$, $\hat{\sigma}$ and $\hat{\lambda}$ are the ML estimates of e_{it}, σ and λ, respectively. As usual in the frontier models, if the variables are measured in logs, a point estimate of the technical efficiency is then provided by $E\hat{F}F_{it} = \exp(-\hat{u}_{it}) \in [0,1]$.

Given the Translog specification in (7), the estimates of TFP change, TC, SE and (TEC)can be computed as follow:

(i) $T\hat{C} = \hat{\gamma}_1 + \hat{\gamma}_2 t + \sum_{j=1}^{4} \hat{\beta}_{tj} x_{jit} + \sum_{m=1}^{8} \hat{\delta}_{mt} D_{mit}$

(ii) $S\hat{E} = (\hat{\varepsilon} - 1)\sum_{j=1}^{4}\left(\frac{\hat{\varepsilon}_j}{\hat{\varepsilon}}\right)\Delta x_{jit}$

where $\hat{\varepsilon}_j = \hat{\beta}_j + \hat{\beta}_{tj} t + \sum_{j=1}^{4} \hat{\beta}_{jl} x_{lit}$, $j = 1,\dots,4$ and $\hat{\varepsilon} = \sum_{j=1}^{4} \hat{\varepsilon}_j$

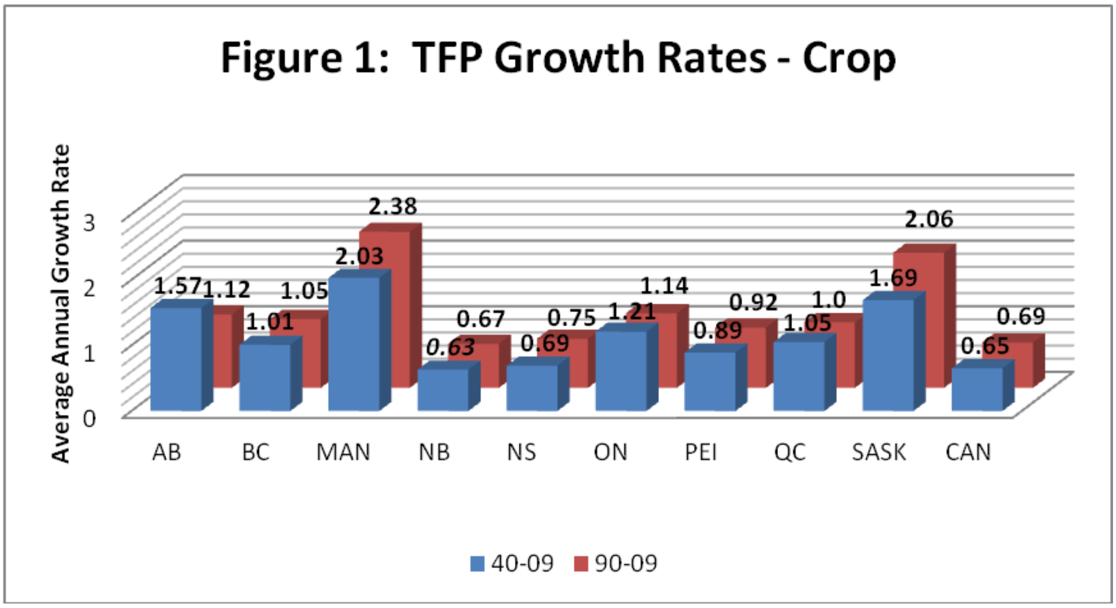
(iii) $\Delta T\hat{E} = \Delta \exp(-\hat{u}_{it})$

(iv) $\Delta T\hat{F}P = T\hat{C} + S\hat{E} + \Delta T\hat{E}$

where the "^" denotes the MLE estimates. Note that, we have used $\Delta x_{jit} = x_{jit} - x_{jit-1}$ to approximate the time derivative $\dot{x}_{jit}$, and similarly for $T\dot{E}$.

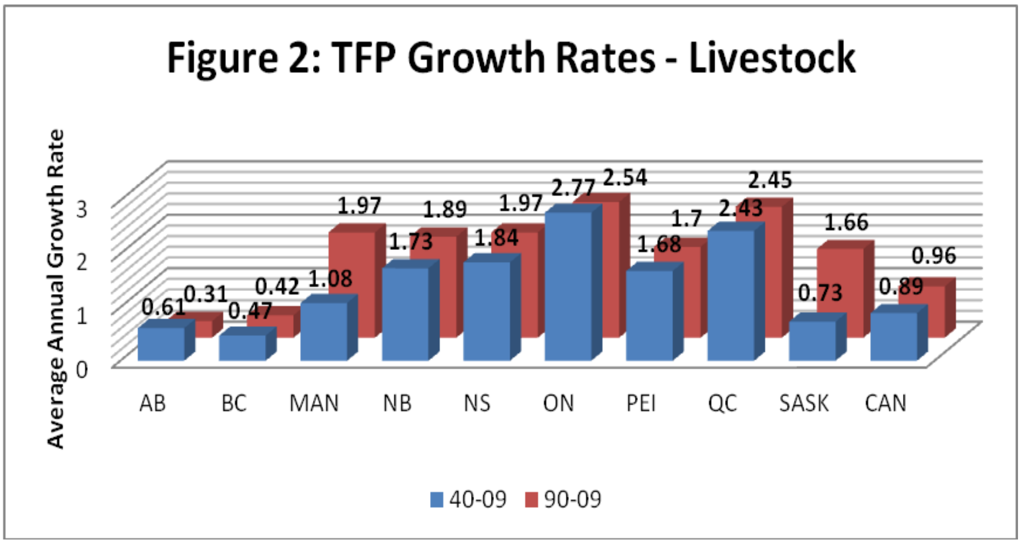
6. Estimation Results

The average annual TFP growth rates for crops and livestock for the entire period are depicted in Figure 1 and 2 respectively. For comparison purposes and to determine if there has been agricultural productivity decline in Canada, we also provided the average annual TFP growth for the last two decades, 1990-2009. It is evident that for each province and Canada, there are notable differences in TFP growth between crops and livestock.



Overall, from 1940 to 2009 the TFP growth rates are on average higher for crops in each of the Prairie provinces, namely Alberta, Saskatchewan and Manitoba, than for the Eastern and Atlantic provinces. For example, the average TFP growth in Alberta, Saskatchewan and Manitoba was 1.57, 1.69 and 2.03% per annum respectively, compare with 1.21% in Ontario, 1.05% in Quebec and less than 1% in Atlantic Provinces. Overall, Canada experienced crop productivity growth of 0.65% per annum.

Comparing average productivity growth in the crop sector for the period 1940 to 2009 to the period 1990 to 2009 we conclude the following. The average crop productivity growth is higher for the period 1990 to 2009 for Saskatchewan (2.06%), Manitoba (2.38%), Nova Scotia (0.75%), Prince Edward Island (0.92%), British Columbia (1.05%), and New Brunswick (0.67%). The overall crop productivity growth in Canada is also higher (0.69). This is clear evidence that recent productivity growth in the crop sector in Canada has not declined. However, crop productivity growth in Alberta (1.12%), Ontario (1.14), and Quebec (1.0%) to 1 are lower for the same period. . For the Prairie Provinces, the finding of crop TFP growth rates in this paper is qualitatively consistent with previous findings in the literature; see for example, Stewards (2006), Stewards et al (2009) and Gray and Veeman (2010).



For livestock, from 1940 to 2009, the TFP growth rates are on average, higher in Eastern and Atlantic Provinces than in the Prairie region. Higher productivity growth rates are found in Ontario and Quebec (2.77% and 2.43% per annum, respectively) followed by New Brunswick, Nova Scotia, Prince Edwards Island and Manitoba. The productivity growth rates for B.C. and the Prairie Provinces with the exception of Manitoba are less than 1% on average while that of Canada is 0.65% per annum.

However, comparing the results to those over the period 1990 to 2009, our results indicated that average livestock productivity growth in Saskatchewan, Manitoba, the Eastern Provinces, Atlantic Provinces and Canada were higher during the last 20 years. Again, the evidence indicates that during the last two decades, productivity growth in the livestock sector has not declined. However, it is noted that Alberta and British Columbia experienced lower livestock productivity growth during the last 20 years. For the period 1990 o 2009 the productivity growth rates in the livestock sub-sector are on the average still higher in Eastern and Atlantic Provinces than in the Prairie region with the exception of Manitoba which has TFP growth rate similar to those of the Atlantic Provinces.

The finding of higher productivity growth rates for crops relative to livestock for the Prairie Provinces compared to Eastern and Atlantic Provinces perhaps, can be explained by longer production cycle and slower progress in controlled genetic technology associated with Cattle production in the Prairie region, especially in Alberta and Saskatchewan. Manitoba is an exception since traditionally, livestock in Manitoba has been more diversified with swine, poultry and dairy; and it is possible that these have been benefited from faster progress in controlled genetics. Conversely, the finding of higher productivity growth rates for livestock relative to crop in Eastern and Atlantic provinces compare to the West, may be due to improvement of genetics, feed conversion and exploitation of economies of scale in the livestock production such as intensive livestock operations especially regarding feedlots and hog barn. Finally, it was noted that productivity growth in Alberta slowed down possibly due to reallocation of resources from agriculture to Alberta's oil and gas sector.

To get more insight into how crops and livestock productivity occurs, we turn our attention to the TFP growth decomposition. Table 3 and 4 provide the decomposition of estimated TFP growth into technical change, scale effects and technical efficiency change. As seen in Table 3, technical change seems to be the dominant component of the estimated productivity growth for crops in in all provinces except Ontario and Quebec as well as for Canada. For example, Alberta, Saskatchewan, Manitoba, New Brunswick and Nova Scotia, from 1940-2009, 88.5%, 85.2%, 79.3%, 73.0% and 69.6% respectively of the TFP growth were driven by technical change.

For these provinces, with the exception of Alberta, the role of scale effects is also economically important ranging from 15.8 % in British Columbia to 33.3% in New Brunswick. The scale effect is much less for Alberta crops with only 6.4% contribution to TFP growth. For Ontario and Quebec, both technological progress (44.6 and 43.8% respectively) and scale effects (52.1 and 45.7% respectively) play important role in the estimated TFP growth. One implication of these results is that the TFP growth in crops is mainly driven by technological progress. This in turn, suggests the vital role of research and development as well as extension activities in the development and adoption of new seed varieties and cropping practice. The change in technical efficiency is mainly positive (except for New Brunswick and Nova Scotia) but has relatively small contributions to the TFP growth for most provinces as well as in Canada. Finally, the residuals which account for the unexplained component of the TFP growth are very small which indicated that factors such as measurement errors and changes in allocative efficiency have very little role in the contribution of productivity growth.

Table 3: TFP Decomposition Results for Crop: 1940 – 2009.

	TFP	Technical Change	Scale Effects	TE Change	Residual
B.C.	1.01	0.81	0.16	0.03	0.01
	(100)	(80.2)	(15.8)	(3.0)	(1.0)
AB	1.57	1.39	0.10	0.06	0.02
	(100)	(88.5)	(6.4)	(3.8)	(1.3)
SK	1.69	1.44	0.21	0.05	- 0.01
	(100)	(85.2)	(12.4)	(3.0)	(-0.6)
MAN	2.03	1.61	0.34	0.07	0.01
	(100)	(79.3)	(16.7)	(3.4)	(0.5)
ON	1.21	0.54	0.63	0.08	- 0.04
	(100)	(44.6)	(52.1)	(6.6)	(3.3)
QC	1.05	0.46	0.48	0.07	0.04
	(100)	(43.8)	(45.7)	(6.7)	(3.8)
N.S.	0.69	0.48	0.22	- 0.04	0.03
	(100)	(69.6)	(31.9)	(-5.8)	(4.3)
N.B.	0.63	0.46	0.21	- 0.05	0.01
	(100)	(73.0)	(33.3)	(-7.9)	(1.6)
P.E.I.	0.89	0.53	0.28	0.05	0.03
	(100)	(59.6)	(31.5)	(5.6)	(3.3)
CAN	0.65	0.43	0.17	0.04	0.01
	(100)	(66.2)	(26.2)	(6.1)	(1.5)

Note: Figures in parentheses denote percentages contribution.

For livestock sector, Table 4 shows that the scale effects play a significant role in TFP growth for all provinces, especially in the Eastern and the Atlantic. In addition, improvement in the degree of technical efficiency is relative significant for the livestock sector. These results suggest that economies of scale associated with the expansion of aggregate livestock output have been the main driver of the productivity growth during the period of 1940 to 2009. Perhaps the main explanation for the role of scale and significant improvement in the degree of technical efficiency in livestock productivity growth is the development and the shift to more intensive livestock operations such as improvement in genetics, feedlots conversion and management practices that have emerged overtime as aggregate provincial output of livestock expand.

The productivity changes in the two sub-sectors were mainly driven by technical changes (such as new seed varieties, progress in controlled genetic technology; better quality machinery and equipment) and scale effects (arising from intensive livestock operations, cropping practices). Specifically, technical change is the dominant component of the estimated productivity growth for crops in all the provinces (AB 88%; SK 85.2%; B.C. 80.2%; MAN 79.3%; N.B 73%; N.S. 69.6%; P.E.I 59.6%) and Canada (66.2%) except Ontario and Quebec. However, the scale effect is the dominant component of the estimated productivity growth for livestock in all provinces (ON 69.3%; QC 65.4%; P.E.I. 62.5%; N.B. 58.4%; N.S. 57.1%; SK 56.2%; MAN 51.9%; B.C. 51.1%; AB 50.8%) and for Canada (58.4%). The contribution of technical progress to productivity growth in livestock was also significant. Finally, though change in technical efficiency is mainly positive (except for New Brunswick and Nova Scotia in the crop sector), its contribution to productivity growth in both sectors were rather very little for the Provinces.

Table 4. TFP Decomposition Results for Livestock: 1940 – 2009.

	TFP	Technical Change	Scale Effects	TE Change	Residual
B.C.	0.47	0.13	0.24	0.08	0.02
	(100)	(27.7)	(51.1)	(17.0)	(4.2)
AB	0.61	0.20	0.31	0.09	0.01
	(100)	(32.8)	(50.8)	(14.8)	(1.6)
SK	0.73	0.23	0.41	0.08	0.01
	(100)	(31.5)	(56.2)	(11.0)	(1.3)
MAN	1.08	0.38	0.56	0.12	0.02
	(100)	(35.1)	(51.9)	(11.1)	(1.9)
ON	2.77	0.72	1.92	0.26	-0.12
	(100)	(29.6)	(69.3)	(9.3)	(-4.7)
QC	2.43	0.61	1.59	0.20	0.03
	(100)	(25.1)	(65.4)	(8.2)	(1.2)
N.S.	1.84	0.64	1.05	0.24	-0.09
	(100)	(34.8)	(57.1)	(13.0)	(-4.9)
N.B.	1.73	0.59	1.01	0.21	-0.08
	(100)	(34.1)	(58.4)	(12.1)	(-4.6)
P.E.I.	1.68	0.48	1.05	0.18	-0.03
	(100)	(28.6)	(62.5)	(10.7)	(-1.8)
CAN	0.89	0.32	0.52	0.06	-0.01
	(100)	(36.0)	(58.4)	(6.7)	(-1.1)

Note: Figures in parentheses denote percentages contribution

7. Concluding Remarks.

Agricultural productivity growth is important with regards to economic efficiency, living standards, international competitiveness, and economic sustainability. Recent studies have concluded that agricultural productivity growth in Canada has been lagging behind that of the United States and many OECD countries. Other research evidence also suggests an economically significant slow-down in agricultural productivity growth in Canada. However, studies by de Avillez (2011a, b) have showed that the Canadian agricultural sector has experienced significant labour productivity growth. Furthermore, some Canadian studies have examined agricultural productivity growth and efficiency for a specific crop or type of livestock farm within a specific province. Regarding technical efficiency, it has been shown by earlier studies that methodological characteristics (estimation technique) and other study-specific characteristics (e.g., functional form, sample size, product analysis, dimensionality, and geographical region or income level for the region where the farm data was collected) could affect the empirical estimates of technical efficiency indicator and lead to conflicting views or evidences.

Hence, to the best of our knowledge, there is no study that examines productivity growth using data on crops and livestock production in all the provinces in Canadian while allowing for production inefficiencies as well as further decomposing TFP growth into scale effects, technical efficiency change and technical change. In this paper, we address the above issues by using a stochastic frontier approach that allows for inefficiencies, and disaggregated agricultural data on crops and livestock from 1940 to 2009 to examine and decompose the TFP growth into scale effects, technical efficiency change and technical change. The paper also investigates if agricultural productivity growth in Canada has recently slowed down.

The results indicate that from 1940 to 2009 the productivity growth rates for the crop sub-sector were on average higher for the Prairie Provinces than for the Eastern and Atlantic Provinces. During the same period, the productivity growth rates in the livestock sub-sector were on the average higher in Eastern and Atlantic Provinces than in the Prairie region with the exception of Manitoba whose TFP growth is similar to Atlantic Provinces for the period 1990 to 2009. Comparing average productivity growth in both the crop and livestock sectors for the period 1940 to 2009 to the period 1990 to 2009 we conclude that for most of the provinces and Canada, the recent average productivity growth rate are higher than the overall average of the entire period. The result implies that there is no evidence of slow-down in agricultural productivity growth in Canada. However, there is evidence suggesting a slow-down in productivity growth in the crop sectors in Alberta and Quebec as well as a slow-down in productivity growth in the livestock sectors in Alberta and British Columbia.

The productivity changes in the two sub-sectors were mainly driven by technical changes (such as new seed varieties, progress in controlled genetic technology; better quality machinery and equipment) and scale effects (arising from intensive livestock operations, and cropping practices). Specifically, technical change is the dominant component of the estimated productivity growth for crops in all the provinces and Canada except Ontario and Quebec. However, the scale effect is the dominant component of the estimated productivity growth for livestock in all provinces and for Canada. The contribution of technical progress to productivity growth in livestock was also significant. Finally, though change in technical efficiency is mainly positive for both sectors (except for New Brunswick and Nova Scotia for the crop sector), its contribution to productivity growth was rather very little for the Provinces.

The decomposition of the TFP growth provides useful insights into the vital role of research and development (R&D) and in turn government support in agricultural sector productivity growth. Government support could include measures such as increasing investment in innovation (for example, improving the stock of knowledge/basic research, new seed varieties, progress in controlled genetic technology, cost-effective cropping practices and livestock operations that also reduce environmental impacts), fostering and facilitating innovation adoption, improving R&D infrastructure and farmers' education. Government policies that promote the development of institutions which would improve farmers' education are very important to ensure that farmers use existing technologies very effectively as well as to introduce new and advanced methods of production.

The productivity growth rate that the Canadian agricultural sector has experienced in the last few decades provides no guarantee that this rate would be attained in the future. A number of recent studies have suggested that among developed countries agricultural productivity growth appears to have slowed significantly during the most recent 10-20 years. The decomposition analysis undertaken in this paper showed that technical progress is an important determinant of productivity growth in Canada. Therefore, increasing funding for agricultural research that increases technical progress is an essential part of the overall agriculture policies. For instance, private and public investment in agricultural science and technology could improve agricultural productivity growth significantly. Hence, there is a need for federal and provincial government intervention to maintain and even increase productivity growth in Canada.

References

Aigner, D., Lovell, C.A.K., and Schmidt, P. (1977). "Formulation and Estimation of Stochastic Frontier Production Function Models." *Journal of Economics* 6: 21–37.

Alston, J. M., Babcock, B. A., and Pardey, P. G. (2010a). Shifting Patterns of Global Agricultural Productivity: Synthesis and Conclusion. In J. M. Alston, B. A. Babcock, and P. G. Pardey (Eds.), *The Shifting Patterns of Agricultural Production and Productivity Worldwide*. Midwest Agribusiness Trade Research and Information Center, Iowa State University, Ames, Iowa.

Alston, J. M.,. Beddow, J. M., and Pardey, P. G. (2010b). Global patterns of crop yields and other partial productivity measures and prices. In J. M. Alston, B. A. Babcock, and P. G. Pardey (Eds.), *The Shifting Patterns of Agricultural Production and Productivity Worldwide*. Midwest Agribusiness Trade Research and Information Center, Iowa State University, Ames, Iowa.

Amara, N., Traoré, N., Landry, R., & Remain, R. (1999). "Technical Efficiency and Farmers' Attitudes toward Technological Innovation: The Case of the Potato Farmers in Quebec". *Canadian Journal of Agricultural Economics, 47*, 31-43.

Bravo-Ureta, B., Solís, D., Moreira López, V., Maripani, J., Thiam, A., & Rivas, T. (2007). "Technical efficiency in farming: a meta-regression analysis". *Journal of Productivity Analysis, 27*, 57-72.

Bruinsma, J. (2009). "The resource outlook to 2050: how much do land, water and crop yield need to increase by 2050"? Paper presented at the Export Meeting on How to feed the World in 2050, Rome, Italy, 24-26 June 2009.

Cloutier L, Rowley R (1993), "Relative Technical Efficiency: Data Envelopment Analysis and Quebec's Dairy Farms." *Canadian Journal of Agricultural Economics* 41: 169–176.

de Avillez, Ricardo (2011a) "A Detailed Analysis of the Productivity Performance of the Canadian Primary Agriculture Sector," CSLS Research Report 2011-06. Prepared for Agriculture and Agri-Food Canada (Ottawa: Centre for the Study of Living Standards). http://www.csls.ca/reports/csls2011-06.pdf

de Avillez R (2011b). "A Half-Century of Productivity Growth and Structural Change in Canadian Agriculture: An Overview." *International Productivity Monitor* 22, pp. 82-99.

Echevarria, C. (1998). "A Three-Factor Production Function: The Case of Canada." *International Economic Journal* 12, pp. 63-75.

Fantino, A.A. and T.S. Veeman (1997) "The Choice of Index Numbers in Measuring Agricultural Productivity: A Canadian Empirical Case Study." In Rose, R., Tanner, C. and Bellamy, M.A., *Issues in Agricultural Competitiveness: Market and Policies*, IAAE Occasional Paper 7: 222-230.

Giannakas K, Schoney R, Tzouvelekas V (2001), "Technical efficiency, technological change and output growth of wheat farms in Saskatchewan." *Canadian Journal of Agricultural Economics* 49: 135–152.

Gray, R. (2008), "Agricultural Research at a Crossroads", Canadian Journal of Agricultural Economics, 56, 1-11.

Green, W.H. (2002), *Econometric Analysis*, Prentice Hall.

Jondrow, J., Lovell, C.A.K., Materov, I.S. and Schmidt, P. (1982). "On the Estimation of Technical Inefficiency in the Stochastic Frontier Production Function Model." *Journal of Econometrics* 19: 233-238.

Kumbhakar S.C. and Lovell C.A.K. (2000). *Stochastic Frontier Analysis*, Cambridge University Press.

Aigner, D.J.; Lovell, C.A.K.; Schmidt, P. (1977). "Formulation and Estimation of Stochastic Frontier Production Functions." *Journal of Econometrics* 6:21–37.

Tsionas, E. G. and S. C. Kumbhakar (2004). "Markov Switching Stochastic Frontier Model." *The Econometrics Journal* 7: 398-425.

Meeusen, W., and van der Broeck, J. (1977). "Efficiency estimation from Cobb–Douglas Production Functions with Composed Error", International Economic Review, 18, 435–444.

Samarajeewa, S., Hailu, G., Jeffrey, S. R., & Bredahl, M. (2011). "Analysis of production efficiency of beef cow/calf farms in Alberta". *Applied Economics*, 1-10.

Statistics Canada. 1991,1996, 2001, 2006. *Census of Agriculture*. Ottawa.

Stewart, B. (2006). *Measures and Causes of Productivity Growth in Prairie Agriculture: 1940-2004*. MS thesis, University of Alberta.

Stewart, B., T.S. Veeman, and J. Unterschultz (2009). "Crops and Livestock Productivity Growth in the Prairies: The Impacts of Technical Change and Scale." *Canadian Journal of Agricultural Economics* 57(September): 379-394.

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

Veeman, T. S., and Gray, R. (2009). "Agricultural Production and Productivity in Canada". *Choices* 24(4).

Veeman, T. S., and Gray, R. (2010). The Shifting Patterns of Agricultural Production and Productivity in Canada. In J. M. Alston, B. A. Babcock, and P. G. Pardey (Eds.), *The Shifting Patterns of Agricultural Production and Productivity Worldwide*. Midwest Agribusiness Trade Research and Information Center, Iowa State University, Ames, Iowa.

Weersink, A., Turvey, C. G., & Godah, A. (1990). "Decomposition Measures of Technical Efficiency for Ontario Dairy Farms". *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie, 38*, 439-456.

APPENDIX A: DATA DESCRIPTION AND METHODODOLOGIES

In this appendix, we provide detail construction of the crop and livestock output and inputs data use in the paper.

Crops

Crop production in Canada is divided into four categories; field crops, potatoes, fruits, and vegetables. Field crops comprise the majority of crop cash receipts in Canada, with the Prairie Provinces having the highest proportions. Saskatchewan has about 98 percent of total crop cash receipts coming from field crops. Field crops include eighteen different types of crops: wheat, barley, rye, mixed grain, corn for grain, buckwheat, dry field peas, and others. A number of smaller specialty crops are not included in total output of field crops; these include Triticale, Canary seed, Fababeans, Coriander, Safflower, Caraway seed, Borage seed, and Chick peas. These were left out of total real production because adequate price information was not available to convert them into real terms. Also, the combined total production of these specialty crops was found to be less than one percent of the total production of all field crops in Canada from 1940-2009, and therefore would not affect total production very much. The data for field crops came from CANSIM table, and the real production value was determined using the Farm Product Price Index (1997=100) as follows:

$$\text{Real production}_t = (\text{nominal value}_t / \text{FPPI value}_t) \times 100$$

The real production of each crop was then added up to obtain a total real production for Canada and each province. The sum of the total real production of all the provinces was then compared to the Canada total. The difference between the two ranged between plus or minus three percent for a given year, but averaged out to be -

0.43 percent over the entire period 1940-2009. This means that on average, total real production for Canada was 0.43 percent lower than the sum of all of the provinces total production. This difference could easily be from rounding errors and the use of an average price of all the provinces at the Canada level.

Potatoes are reported separate from field crops by Statistics Canada. Potatoes comprise about five percent of total crop cash receipts in Canada, with Prince Edward Island having the largest portion of cash receipts coming from potatoes at 81 percent. The production of potatoes was converted to real production using the 1997 average farm price for each province.

Livestock

Livestock output was found using farm cash receipts from 1947 to 2009. The total production of livestock is comprised of the production of cattle, calves, hogs, sheep, lambs, dairy products, poultry, eggs, and other livestock and products. These are the nominal values of livestock production. The farm product price index (FPPI) is then used to convert the production into real terms as follows:

$$\text{Real production}_t = (\text{nominal value}_t / \text{FPPI value}_t) \times 100$$

The FPPI did not report values for individual livestock products (cattle and calves, hogs, poultry, eggs, dairy) prior to 1981. However, a total livestock and animal products index is reported from 1971 on, and prior to this the total index value is reported back to 1935. Therefore, the missing values from 1947 to 1981 have been estimated using a moving average:

$$\text{FPPI}_t = \text{Average}(\text{FPPI}_{t-1} \text{ to FPPI}_{t-12}) / \text{Average}(\text{FPPI}_{t-2} \text{ to FPPI}_{t-13})$$

This data was reported monthly so a twelve period (one year) moving average is used as it yielded the most reasonable trend when compared to five-year or longer period moving averages. A yearly average of the index was then used in the transfer of livestock production from nominal to real terms.

After the farm cash receipts were changed into real terms, an inventory adjustment was done to account for any sales of livestock products that were produced the previous year and production in the current year, which was not sold. Yearly closing stock values were used to do this, with the closing stock of one year equal to the opening stock of the following year. The FPPI was used to transform these opening/closing stocks into real terms.[2] Therefore, the real value of production is equal to the real value of livestock cash receipts plus the real value of the inventory adjustment (closing – opening stocks):

$$\text{Real value of production} = \text{Real value of farm cash receipts} + \text{Real value of closing stocks} - \text{Real value of opening stocks}$$

Dairy products are the only category that did not have an inventory adjustment. This is because inventory production data was not available. It was believed that, because dairy products are perishable, inventory would be small or non-existent and thus have little effect on production levels.

<u>Inputs</u>

The input data has been organized following Stewart (2006). The data is organized into four main categories; capital, land, labour, and materials. Capital contains the value of machinery and equipment used in production, the cost of repairs to

[2] Inventory adjustment is seen in the "Real and Inventory Adjusted" tab of the livestock output file. Inventory data comes from various sources which are outlined detailed in the file by product.

machinery and equipment, the depreciation value of machinery and equipment, and the value of livestock inventory. Land is comprised of the value of cropped land, land in summer fallow, pasture land, buildings, building repairs, building depreciation, and property tax. Labour contains unpaid and paid labour. Materials include the cost of fuel, electricity, telephone, custom work, twine, business and crop insurance, fertilizer and lime, pesticides, commercial seed, feed, artificial insemination and vet fees, and miscellaneous other expenses.[3]

Capital inputs come from three different tables. Table 002-0007 contained the data needed for machinery and equipment, and livestock inventories. It is reported in thousands of dollars and covered the entire span of this study, 1940-2009. Repair and depreciation values come from two separate tables, the values for 1940-1970 come from table 002-0015 and for 1971-2009 table 002-0005 is used. Both are reported in thousands of dollars. The only manipulation made in the capital section was for the value of machinery and equipment repairs for the year 1950. This had to be extrapolated using data from the previous and following year.[4] Prior to 1950, fuel costs were included under the category of "machinery repairs and other machinery expenses". After 1950, fuel costs are reported separately, and are recorded in the materials section of inputs.

Most of the data for land inputs come from the same tables as capital inputs. Land and building values come from table 002-0007, depreciation, property tax, and building repair values come from table 002-0005 and table 002-0015. Building repairs include any costs of repairing fences as well. Cropped land data was obtained from table 001-0017, and is calculated as the total area, in acres, of seeded land. Pasture land data is

[3] All of this data is contained in the file Total Inputs, it is in both nominal and real terms.
[4] This can be seen in the file "farm operating expenses and depreciation charges, table 002-0015".

from table 001-0037 for the years 1951-1992. The years prior to and following this time period was estimated using a five year moving average.[5]

$$\text{Pasture land}_{t} = \text{pasture land}_{t-1} \times \frac{[(\text{average pasture land for periods t-1 to t-5})}{(\text{average pasture land for periods t-2 to t-6})]}$$

Labour consists of unpaid and paid labour; paid labour is separated into hired labour and operator labour in the nominal section of labour inputs. Hired labour consists of paid wages to employees and family members and was obtained from table 002-0015 for the years 1940-1970, and table 002-0005 for 1971-2009. These paid wages include room and board as well as cash wages, and the value before rebates was used. Statistics Canada defines operators as those persons responsible for the management decisions made in the operation of a census farm or agricultural operation, and up to three operators can be reported per farm. The net income received by farm operators from farm production was taken as the value of operator labour, from table 380-0052.[6] Unpaid labour was calculated as 70 percent of operator labour, following Veeman and Fantino (1985).

Data for the materials section came from table 002-0005 and table 002-0015. The cost of containers is included in pesticides from 1940-1947, after this it was included along with twine and wire. This is the reason for the drop in pesticide costs between 1947 and 1948.[7] Irrigation data was only reported for Canada, Saskatchewan, Alberta, and British Columbia. The cost of irrigation for Canada is equal to the sum of the cost of irrigation for Saskatchewan, Alberta, and British Columbia.[8] Twine, wire and containers are reported together starting in 1970, prior to this they were reported separately except for the period where containers were included in the cost of

[5] File "Pasture area, table 001-0037"
[6] File "Net income received by farm operators, table 380-0052"
[7] The value of pesticides or containers for the period 1940-1947 was not available so the two could not be separated from "pesticides and containers".
[8] This was the value given for Canada in table 002-0015 and 002-0005, it was not calculated.

pesticides, as mentioned before. Therefore, the cost of twine, wire and containers was calculated by adding the three values together until 1970 when they were reported together. Artificial insemination and veterinary expenses were also reported together starting in 1970, prior to this they were reported separately and thus were added together. The cost of electricity, telephone, custom work, and business insurance are taken as is from the tables and are reported starting in 1951. Crop insurance is also taken as is but it is not reported before 1971.

The preceding comprises the nominal value of inputs; this was converted into real value using the farm product price index. The following conversion formula was used:

$$\text{Real Value}_t = (\text{Nominal Value}_t / \text{input price index value}_t) \times 100$$

Some inputs had no input price index (IPI) so alternatives were required. For depreciation of machinery and equipment (M & E), and buildings the asset IPI was used. Therefore, IPI for M & E is used for the depreciation of M & E, while the IPI of building is used for the building depreciation. Some inputs had not IPI so the average yearly price was used to convert them into real terms. The input was divided by the current year price per unit, and then multiplied by the 1997 base year price. This was done for and land values such as summer fallow, cropped land, and pasture land.

Allocating Inputs

Allocating inputs between the livestock and crop sectors requires the use of census of agriculture data, which is more detailed and separates data by farm type. These farm types are categorized as follows: wheat, fruits and vegetables, field crops, cattle, hogs, poultry, mixed farms, and subsistence farms. To be categorized as one of these at least 51 percent (50 percent prior to 1961) of total output must come from the titled crop (i.e. a farm classified as a cattle farm must have 51 percent of its total output coming from cattle production). In some census years mixed farms are subdivided into mixed livestock farms, mixed crop farms, and mixed other. A mixed crop farm is a farm that has 51 percent of its total production from two or more crop categories (wheat, fruits and vegetables, field crops). When retrieving the required data, it is recorded as livestock sector or crop sector, with livestock being equal to the sum of all farms classified as cattle, hogs, poultry, and mixed livestock. The crop sector is the sum of all farms classified as wheat, fruits and vegetables, field crop, and mixed crop farms. Further categories are later added on including grain farms, dairy farms, and fruits and vegetables are separated.

The required data is cropped land, livestock capital, operator labour, paid labour, and the value of land and buildings. This is all separated between crops and livestock.[9] After the data was recorded, the share of each category (cropped land, livestock capital, etc.) was determined for each sector following the methodology outlined by Stewart (2006). Most of the census data was retrieved from published Census of Agriculture documents in the University Library. These sector shares were then used to allocate the inputs between the Livestock and Crop sectors. The share of machinery and equipment was used to allocate all of the Capital inputs except livestock Inventory, which did not require allocation as it is solely a livestock input. The allocation was completed by simply taking the total input value of capital and multiplying it by the sector share. All Land inputs were allocated using the sector share of the value of land and buildings. Some land was only used for one sector; cropped land and summer fallow land are entirely crop inputs while pasture land is

[9] The file “Census Data Requirements” contains all this data; it is categorized by census year, and province. The table number from which the data was obtained is also recorded for each census year.

exclusively a livestock input. Two sector shares were used to allocate Labour inputs. The share of operator labour was used to allocate unpaid labour as well as operator labour, while the share of paid labour was used to allocate paid wages.

This leaves the inputs in the materials category to be allocated. Irrigation, fertilizer and lime, pesticides, commercial seed, and crop insurance are solely a crop sector input while feed, artificial insemination and vet expenses are livestock sector inputs and thus do not need to be allocated. The remaining materials inputs are allocated using one of the above methods or on the crop and livestock's share of value of total output. Fuel is allocated using the capital shares, electricity using the land and building shares, and telephone using the labour share. Custom work, miscellaneous expenses, business insurance, and twine, wire, and containers are allocated using the crop and livestock's share of value of total output. This was done using the total crop cash receipts and total livestock cash receipts as proxies for the value of total crop output in each year.