Measurements of Agricultural Productivity and Efficiency Gains from NAFTA

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Abstract

The primary objective of this study is to empirically determine whether North American Free Trade Agreement (NAFTA) has contributed to increased agricultural productivity in any of its member countries. Implementation of the NAFTA began on January 1, 1994. This agreement removed most barriers to trade and investment among the United States, Canada, and Mexico, in which all non-tariff barriers to agricultural trade between these countries were eliminated. Data Envelopment Analysis (DEA) and the Malmquist Productivity Index were used to estimate the total factor productivity change, technical change, and efficiency change of agricultural production for each NAFTA country. Then, using time series data, the efficiency changes in countries were compared to determine whether NAFTA has been beneficial to the agricultural sector of a member country. , Total factor productivity, technical change, and efficiency change of agricultural production in NAFTA countries were analyzed for the period 1980-2007, and then a comparison between pre- and post-NAFTA periods was also made. In the analysis, aggregate agricultural production was used as the output, and five variables were considered as the inputs, which included: land, labor, capital, fertilizer and livestock. The results revealed that the average annual total factor productivity increased by 1.6 percent during the 1980-2007 period for NAFTA countries, mainly coming from technical change. Total factor productivity did not change obviously during the pre-NAFTA period. In contrast, it increased by 2.7 percent due to technical improvements in post-NAFTA period. Consequently, it is noticeable that compared to the pre-NAFTA period, the countries especially Mexico performed better by achieving higher levels of productivity in agricultural production.

Keywords: Agricultural Efficiency, Data Envelopment Analysis, Malmquist Index, NAFTA, Total Factor Productivity

Introduction

Implementation of the North American Free Trade Agreement (NAFTA) began on January 1, 1994. The U.S. Congress approved NAFTA after an intense political debate. NAFTA supporters believed that trade liberalization will create gains through increased trade. On the other hand, opponents voiced a number of concerns about the impact of the agreement on U.S. labor markets. They argued that imports from Mexico accompanied by surging capital flows to Mexico would destroy jobs in the United States (Burfisher, Robinson and Thierfelder, 2001). Some concerns were more subtle and they are related to the effects trade liberalization of Mexican agriculture would have on unskilled labor market transitions in that country to the United States. Moreover, some scientific work based on empirical analyses have found that trade liberalization accounts for some of the fall in demand for blue-collar workers in developed countries, and that the contribution of trade is small and by far the bigger culprit is trade-independent technological change (Krugman, 1995). Studies that quantified the long-term effects of NAFTA claimed Mexico would be the country to benefit the most from NAFTA. The United States would benefit a little, and Canada and the rest of the world will obtain practically no gain (Kouparitsas, 1997).

The primary objective of this study was to empirically determine whether NAFTA has contributed to increased agricultural productivity in any of these countries. This overall objective was achieved by pursuing the following specific objectives: 1-To estimate the total factor productivity change (TFP), technical change (TC) and efficiency change (EC) of agricultural production for each NAFTA country; and 2-To compare the productivity change using time series data to determine whether NAFTA has been beneficial to the agricultural sector of a member country. The authors also tested for the hypothesis whether NAFTA has been beneficial equally to all member countries. The alternative was that the developing country among them will benefit more than the other countries because of initially low agricultural productivity growth rate.

Reviewed Literature Studies on Productivity and Efficiency

Agricultural productivity and efficiency have been measured and compared among countries to determine productivity gaps, technological problems and inefficient production in numerous regions and international trade entities by using data envelopment analysis (DEA) and the Malmquist productivity index. Productivity growth in 17 OECD countries (Färe et al., 1994), agricultural productivity differences within European Union (Serrao, 2003), and the patterns of agricultural productivity growth in 16 Middle East and North Africa (MENA) countries (Belloumi and Matoussi, 2009) were examined by measuring technical change and efficiency change using the Malmquist productivity index. Total factor productivity, technical change, and efficiency change in developed or developing countries were measured to expose the reasons leading to agricultural productivity differences caused by technological improvements and resource utilization discrepancies (Arnade, 1998; Fulginiti and Perrin, 1998; Coelli and Rao, 2003; Trueblood and Coggins, 2003; Alauddin, Headey and Rao, 2005) by employing DEA and the Malmquist index.

The efficiency of a production unit involves the comparison between observed and optimal amount of its output and input (Lovel, 1993). Furthermore, technical efficiency is the ability of obtaining maximum output by using a certain amount of input. There are two approaches for measuring efficiency: 1-input oriented approach which measures technical inefficiency as proportional increase in input use keeping output constant (Farrel, 1957); and 2-technical inefficiency; this can be measured as a proportional increase in output keeping input use constant. This is called output-oriented approach.

The Parametric Model

DEA is commonly used to evaluate the efficiency of Decision Making Units (DMUs). DEA, a non-parametric mathematical programming method is derived from Farrel (1957) definition of efficiency. It involves the use of linear programming to construct an efficiency frontier (piece-wise). The frontier provides a relative measurement of each unit. The frontier that comprises efficient units is the expected target for other units which are inefficient.

The first DEA model was suggested by Charnes, Cooper, and Rhodes (1978) and was based on the assumption of constant return to scale (CRS). In this study, output oriented CRS model, which is a form of envelopment is used to measure efficiency of agricultural production is mathematically presented as below.

$$\begin{aligned} & Max_{\lambda,\theta}\theta \\ st.\quad & \theta y_i + Y\lambda \geq 0 \\ & x_i - X\lambda \geq 0 \\ & \lambda \geq 0 \end{aligned} \tag{1}$$

where θ is scalar and is the i^{th} unit's efficiency score ; and λ is a vector of constants in Nx1 matrix; where; i=1,2,3. The estimated θ should be (θ ≤ 1); and (θ =1) indicates a technically efficient country in agricultural production. Solving the above linear programming problem for the three NAFTA countries yields three θ parameters. The y_i in the equation set is the level of agricultural production from the i^{th} country; Y is a (1x3) matrix depicting the agricultural production levels for the three. Lastly, the x_i is the i^{th} country's level of input use which is a 5x3 matrix. The inputs are land, agricultural labor, capital, fertilizers and livestock.

Banker, Charnes and Cooper (1984) re-developed the DEA model, which assumes (CRS). This was achieved by using Variable Return to Scale (VRS). The use of the CRS specification when all firms not operating at the optimal scale, results in measures of Technical Efficiency (TE) which are confounded in Scale Efficiencies (SE). The use of the VRS specification permits the calculation of these SE effects (Coelli et al, 1998). The CRS linear programming problem can be easily modified to account for VRS by adding the convexity constraint $N1'\lambda = 1$ (Nx1 vector of ones) to equation (1).

Overall, the Technical Efficiency measure (TE_{CRS}) obtained from CRS DEA is decomposed into pure technical efficiency variable returns to scale (TE_{VRS}) and scale efficiency (SE). A difference in CRS and VRS TE scores for a particular country indicates the country has scale inefficiency and that the scale inefficiency can be calculated from the difference between the VRS and CRS TE scores. Scale efficiency represents the losses due to non-optimal production size (Färe et al, 1985). The decomposition of scale efficiency yields Pure Technical Efficiency (PE). The purpose of the decomposition is to determine the source of inefficiency.

Aggregate productivity refers to the amount of output obtained from given levels of inputs in a sector (Fulginiti and Perrin, 1998). In this study, productivity refers to the productivity of total factor or multifactor inputs used in agricultural production.

We defined the Malmquist index using distance functions. Distance function allows one to describe a multi-input -multi-output production technology without the need to specify a behavioral objective. The Malmquist total factor productivity (TFP) index measures the TFP change between two data points by calculating the ratio of the distances of each data point relative to a common technology. The Malmquist (output-oriented) TFP change index between any two periods, *s* (the base period) and period *t* is given by

$$m_o(y_s, x_s, y_t, x_t) = \frac{d_o^t(y_t, x_t)}{d_o^s(y_s, x_s)}\left[\frac{d_o^s(y_t, x_t)}{d_o^t(y_t, x_t)} \times \frac{d_o^s(y_s, x_s)}{d_o^t(y_s, x_s)}\right]^{1/2} \qquad (2)$$

where the notation $d_o^s(y_t, x_t)$ represents the distance from the period t observation to the period s technology. A value greater than 1 indicates a positive TFP growth from period s to period t while a value less than 1 implies a TFP decline. Also, the ratio outside the square brackets denotes the change in the output-oriented measure of TE between period s and t. The remaining part of the index is a measure of TC (Coelli et al, 1998).

The Malmquist Productivity Index (TFP) is decomposed into TC and efficiency change (EC) indices with DEA (Fare et al., 1994; Arnade, 1998). This decomposition allows measuring the contribution of TC and EC in the productivity increase. A change in TFP is calculated by multiplying TC and EC indices. An efficiency index measure of 1 implies a country lies on a "best practice" frontier while an index measure less than 1 denotes an inefficient employment of agricultural factors of production.. Any efficiency index subtracted from 1, indicates a larger proportion output can be increased without increasing inputs. Besides, the overall EC can be decomposed into pure technical efficiency change (PEC) and scale efficiency change (SEC) in order to find the source of inefficiency. EC can be calculated by multiplying PEC and SEC. The average annual changes of the TFP and their components for each country in the study period are presented. The estimated indices are greater than 1, when any improvement occurs.

Data

Three time periods: overall 1980-2007, (pre- and post-NAFTA); 1980-1994 and 1994-2007 were created for the analysis of TFP, TC and EC. The productivity measurement considers one output and five input variables. Data on agricultural output and inputs- land, labor, capital, fertilizer and livestock was obtained from the FAO website (http://faostat.fao.org). The FAO output concept is the output from the agricultural sector net of quantities of various commodities. The agricultural inputs: 1-land, which includes all crops and permanent pasture; 2-labor, which covers the economically active population in agriculture; 3-capital, which covers the number of tractors, harvesters and threshers used in agriculture; 4-fertilizer, which refers to the total amount of consumed nitrogenous, potash and phosphate; and 5-livestock, which covers the number of buffaloes, cattle, goats, pigs and sheep. The number of these animals is converted into sheep equivalent using conversion factors of 8 for buffalo and cattle, and 1 for sheep, pigs and goats.

Results and Discussions

Figure 1 presents the efficiency measures by countries. The technical efficiency measures for NAFTA countries over all periods (pre- and post- NAFTA, 1980 to 2007) indicated U.S. and Mexico are consistently efficient. It is clear that these two countries utilized all of their resources efficiently and their productivities lie above the efficiency frontier. They are therefore referred to as best practicing countries. Canada was technically inefficient in most years which means Canada produced less agricultural output with existing resources and this decreased the overall average efficiency of NAFTA countries.

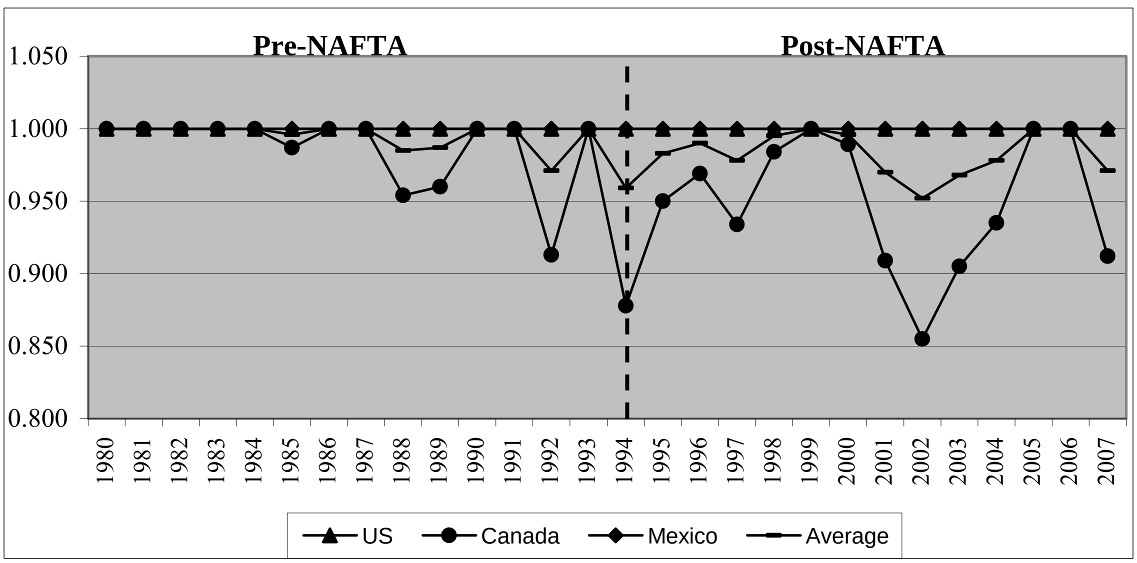

Figure 1: Efficiency Measures by Countries, 1980-2007

Table 2 shows the Malmquist productivity indices by years from the 1980-2007 period. When efficiency indices were evaluated, PEC was 1 in all years, indicating the countries obtained maximum output by using the current level of inputs. The main source of the overall inefficiency was scale inefficiency which implies that inputs allocation was inefficient. The TC index is also greater than 1 in most years, which implies that there was an improvement in technology, especially in post-NAFTA period. Increase in TFP can be attributed to TC rather than EC in most years.

Although the efficiency declined most rapidly (0.958) as a result of scale inefficiency, TC increased by 12.8%. Therefore, TFP increased by 8% in the year NAFTA was established.

Table 2: The Results of Malmquist Indices, (1980-2007)

Pre/ Post-NAFTA	Year	TFP	TC	EC	PEC	SEC
Pre-NAFTA	1981	1.047	1.047	1.000	1.000	1.000
	1982	1.021	1.021	1.000	1.000	1.000
	1983	0.913	0.913	1.000	1.000	1.000
	1984	1.036	1.036	1.000	1.000	1.000
	1985	1.050	1.054	0.996	1.000	0.996
	1986	1.005	1.001	1.004	1.000	1.004
	1987	0.976	0.976	1.000	1.000	1.000
	1988	0.936	0.951	0.984	1.000	0.984
	1989	1.026	1.024	1.002	1.000	1.002
	1990	1.070	1.055	1.014	1.000	1.014
	1991	1.010	1.010	1.000	1.000	1.000
	1992	1.017	1.048	0.970	1.000	0.970
	1993	0.960	0.931	1.031	1.000	1.031
Post-NAFTA	1994	1.080	1.128	0.958	1.000	0.958
	1995	1.047	1.020	1.027	1.000	1.027
	1996	0.999	0.992	1.007	1.000	1.007
	1997	1.033	1.046	0.988	1.000	0.988
	1998	1.018	1.000	1.018	1.000	1.018
	1999	1.055	1.049	1.005	1.000	1.005
	2000	1.013	1.017	0.996	1.000	0.996
	2001	0.980	1.008	0.972	1.000	0.972
	2002	0.995	1.015	0.980	1.000	0.980
	2003	1.060	1.040	1.019	1.000	1.019
	2004	1.038	1.027	1.011	1.000	1.011
	2005	1.041	1.018	1.023	1.000	1.023
	2006	1.024	1.024	1.000	1.000	1.000
	2007	0.996	1.027	0.970	1.000	0.970

Note: TFP: Total Factor Productivity Change, TC: Technical Change, EC: Efficiency Change, PEC: Pure Efficiency Change, SEC: Scale Efficiency Change

Average TFP, TC and EC for countries over the period 1980-2007 were computed (see Table 3). On the average, TFP increased by 1.6% (1.016) in the entire period. TC also increased by almost the same magnitude (1.017). This resulted from the fact that average efficiency (0.999) of countries was almost equal to 1.00. Canada and U.S. represented the countries with the highest productivity increase, 2.1% and 1.9%, respectively. TFP and TC were equal in U.S. due to efficient agricultural production. Although TC increased by 2.4%, productivity rose less due to inefficiency (0.997) in agricultural production in Canada. Mexico recorded a very low productivity increase, which was probably due to low technological improvement (1.007). Generally, U.S. and Mexico were efficient in agricultural production over the entire study period (1980-2007).

Table 3: Average Productivity and Efficiency Changes by Countries, 1980-2007

Country	TFP	TC	EC	PEC	SEC
U.S.	1.019	1.019	1.000	1.000	1.000
Canada	1.021	1.024	0.997	1.000	0.997
Mexico	1.007	1.007	1.000	1.000	1.000
Average	1.016	1.017	0.999	1.000	0.999

Note: TFP: Total Factor Productivity Change, TC: Technical Change, EC: Efficiency Change, PEC: Pure Efficiency Change, SEC: Scale Efficiency Change

Table 4 presents the average productivity and efficiency changes by countries comparatively between pre- and post-NAFTA. Overall, the average increase in TFP was only 0.4%. The U.S. had the highest productivity increase (1.7%), resulting from TC. The productivity change in Canada was 1.2%; the same as TC and average efficiency score was 1.000. Even though Mexico was efficient, TFP was declining (-1.6%) due to technological regress.

The average annual productivity change was 2.7% in post-NAFTA. Over the pre-NAFTA period, only Mexico had a declining TFP (0.984). Nevertheless, it had one of the highest TFP with 2.9% average annual change in post-NAFTA period. Canada had the highest level of TC (1.036). However, the TFP (1.029) was the same with Mexico (0.993) because of the inefficiency in agricultural production. The average annual productivity change was 2.2% in the U.S., and it all resulted from technology improvement. Overall, TFP increased in all countries when compared between pre- and post- NAFTA, as well as TC.

Table 4: Average Productivity and Efficiency Changes by Countries between Pre-NAFTA (1980-1993) and Post-NAFTA (1994-2007)

	Pre-Nafta			**Post-NAFTA**		
	TFP	TC	EC	TFP	TC	EC
U.S.	1.017	1.017	1.000	1.022	1.022	1.000
Canada	1.012	1.012	1.000	1.029	1.036	0.993
Mexico	0.984	0.984	1.000	1.029	1.029	1.000
Average	1.004	1.004	1.000	1.027	1.029	0.998

Note: TFP: Total Factor Productivity Change, TC: Technical Change, EC: Efficiency Change, PEC: Pure Efficiency Change, SEC: Scale Efficiency Change

Conclusions

Data Envelopment Analysis (DEA) and the Malmquist Productivity Index were applied to determine whether NAFTA has contributed to increased agricultural productivity in any of its member countries by estimating the total factor productivity change, technical change and efficiency changes. Mexico experienced an improvement in technology in post-NAFTA which led to productivity gain. Since it only occurred in the post-NAFTA period, we can attribute this gain to NAFTA. This result is consistent with one of the primary objectives of establishing NAFTA. Canada and U.S. considered using international trade as a tool to develop the Mexican economy in order to curtail migration up north and the result is consistent with trade theory. International trade can be used to develop economies. A developed Mexican economy will be able to provide employment for its citizens to reduce migration to the U.S. and Canada. So in conclusion the implementation of NAFTA has helped develop at least, the agricultural economy of Mexico by increasing productivity, which has the potential to curtail immigration of unskilled labor traveling from Mexico to the U.S. and Canada.

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