Induced Innovation in Canadian Agriculture

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Annotation: The study re-examines the induced innovation hypothesis from 1958-2006 in Canadian agriculture for two regions in Canada: Central Canada (Provinces of Ontario and Quebec) and Western Canada (Provinces of Alberta Saskatchewan and Manitoba). There is broadly consistent support for the induced innovations hypothesis for Canadian agriculture, especially for Western Canadian Agriculture. In addition, there is support for the notion the US as well as Canadian research expenditures are important to the explanation of input ratio movements in Canadian Agriculture in the long run. This could indicate the existence of spillover effects that run from US agricultural research to Canadian Agriculture.

Key words: Induced Innovation; factor substitution; spillover effects; non-stationarity; cointegration

1 Introduction

Technical change is important in global agriculture and it is widely studied and prescribed by policy makers. A related issue is induced innovation, a concept first introduced by Hicks (1932), refined by Hayami and Ruttan (1971), Ahmad (1966), and de Janvry et al. (1989).

> "Changes in relative prices of factors are expected to induce development and implementation of new technology to save the relatively more expensive inputs" (Liu & Shumway, 2009)

By 1990, it had become a stylized fact in the US that technical change was consistent with the induced innovation hypothesis (IIH). In Canada, a 1990 paper by Karagiannis and Furtan also found support for this hypothesis.

However, recently the induced innovation hypothesis has come under challenge. Omstead and Rhode's research (1993 and 1998) suggested that the IIH should be reconsidered for US agriculture. Lambert and Shonkwiler (1995) and Thirtle et al. (2002) found support for the IHH in US agriculture. Lin (1998) rejected the hypothesis as did Machado (1995), Tiffin and Dawson (1995) and Liu and Shumway (2009).

It has been almost a quarter of a century since the publication of the Karagiannis and Furtan study of induced innovation in Canadian agriculture. A re-examination of this topic for Canadian agriculture seems timely. Our study updates the Karagiannis and Furtan study by:

- Extending the time series from 1985 to 2006
- Adding research expenditures as well as a time trend as a proxy for technical change
- Updating the econometric technique to use modern time series analysis
- Estimating the two state CES model
- Adding US research expenditures to examine spillover effects

2 Discussion of Theoretical Model and Empirical Implications of the Induced Innovations Hypothesis

The model used by Karagiannis and Furtan (1990), Thirtle et al. (2002) and Liu and Shumway (2009) is the two stage CES function. This function assumes the machinery/labour input pair is separable from land/fertilizer input pair and that the overall function is homogeneous of degree one. This leads to a long run specification of the two equations:

$ln(M_t /L_t) = \beta_0 -\sigma_1 \, ln(P_{M\,t} /P_{L\,t}) +(1- \sigma_1) \, ln(E_t)$, (1) and

$ln(F_t /A_t) = \alpha_0 - \sigma_2 \, ln(P_{F\,t} /P_{A\,t}) +(1- \sigma_2) \, ln(E_t)$, (2)

where σ_1 is the elasticity of substitution between machinery and labour, σ_2 is the elasticity of substitution between fertilizer and land, M_t is the quantity of machinery, L_t is the quantity of labour, F_t is the quantity of fertilizer, A_t is the quantity of land, P_{Mt} is the price of machinery, P_{Lt} is the price of labour, P_{Ft} is the price of fertilizer, P_{At} is the price of land and E_t is technological progress.

According to Liu and Shumway (2009) and Thritle et al. (2002), the induced innovations hypothesis implies the following empirical implications associated with equations (1) and (2):

1) All variables in the system are balanced. Assuming the variables in model are integrated, then this implies that the variables are I(1);

2) There are two cointegrating vectors given the stochastic variables in the system. There is one cointegrating vector for the machinery/labour equation and one cointegrating vector for the fertilizer/land equation;

3) Factor prices and quantities are negatively correlated over the long run;

4) Current factor prices do not completely explain factor substitution; and

5) Causality runs from prices to quantities but not quantities to prices.

In addition to empirically testing these five implications of the IIH for Canadian data, this study tests three additional implications of the model. The first relates to the choice of the two stage CES function. Karagiannis and Furtan (1990), Thirtle et al. (2002) and Liu and Shumway (2009) all maintain the two stage CES functional form to study the IIH. The unrestricted two long run equations studied are:

$ln(M_t /L_t) = \beta_0 + \beta_1 \, ln(P_{M\,t} /P_{L\,t}) + \beta_2 \, ln(P_{F\,t} /P_{A\,t}) + \beta_3 \, ln(E_{ct}) +\beta_4 \, ln(E_{USt}) + \beta_5 t$, (3) and

$ln(F_t /A_t) = \alpha_0 + \alpha_1 \, ln(P_{M\,t} /P_{L\,t}) + \alpha_2 \, ln(P_{F\,t} /P_{A\,t}) + \alpha_3 \, ln(E_{ct}) +\alpha_4 \, ln(E_{USt}) + \alpha_4 t.$ (4)

Comparing equation (1) with equation (3) and equation (2) with equation (4), then the following restrictions are implied:

$\beta_1 + \beta_3 = -1, \beta_2=0,$ and $\beta_3 = \beta_4.$ (5)
$\alpha_2 = 0, \alpha_2 + \alpha_3 = -1,$ and $\alpha_3 = \alpha_4.$ (6)

This will be called empirical implication 6.

Also, this study is different than previous studies in the both Canadian as well as US research expenditures are used as a proxy for technological progress. Therefore, the fact that US research expenditures matter in equations (3) and (4) implies the test $\beta_4 = \alpha_4 = 0$ will be implemented.

This will be called empirical implication 7.

A final test of the IIH that will be undertaken that is not discussed by previous authors is an additional causality test than the test where prices cause quantities (implication (3) above). Since research expenditures are used as a proxy for technological change and the IIH assumes that prices induce innovations, it seems reasonable the prices cause research expenditures.

This will be called empirical implication 8.

3 Data and Results

3.1 Discussion of Data

The data on prices and quantities from 1935-85 are taken from Karagiannis and Furtan (1990). The original dataset contains annual observations from 1935 to 1985, for price and expenditure on land, machinery, fertilizers and chemicals and labour (Statistics Canada, 2009 and various years). The data from 1985-2006 were taken from a study by Clark et al. (2012) who updated the Karagiannis and Furtan data to study cost and distance functions. The data for research Canadian research expenditures (1956-2007) were compiled from Statistics Canada data sources. United States research expenditures from 1890-1990 are taken from Thirtle et al. (2002) and updated to 2006 from their US data sources. The longest overlapping time period for all data was 1958-2006. All data were normalized by the 2006 observation (therefore 2006=1.0).

3.1 Discussion of Results

Recall that empirical implication (1) implies that all the stochastic variables in the system are required to be I(1). This implication is tested using an augmented Dickey – Fuller (1979) (ADF) test. Table 1 presents the results of performing an ADF test on the stochastic variables in the system.

Table 1: Augmented Dickey Fuller Tests on Data (1958-2006)

Variable	Deterministic Variables included in Dickey Fuller Regression			
	Western Canada		Central Canada	
	Intercept	Intercept, trend	Intercept	Intercept, trend
Natural log of M/L	-1.29	-1.16	-2.28	-2.98
	(1)	(1)	(2)	(2)
Natural log of F/A	-2.09	-1.77	-3.40	-1.19
	(1)	(1)	(0)	(0)
Natural log of P_M/P_L	-1.43	-0.67	-2.40	-1.59
	(1)	(1)	(1)	(1)
Natural log of P_F/P_A	-1.84	-0.04	-2.32	-1.09
	(0)	(0)	(0)	(0)
	Western Canada & Central Canada			
	Intercept		Intercept, trend	
Natural log of RES_C	-1.82		-0.23	
	(0)		(0)	
Natural log of RES_{US}	-1.11		-1.60	
	(0)		(0)	

Note: (1) M=Machinery, L=Labor, F=Fertilizer, A=Land, P_M=Price of Machinery, P_L=Price of Labor, P_F=Price of Fertilizer, P_A=Price of Land, RES_C=Agriculture Research Expenditure in Canada, RES_{US}=Agriculture Research Expenditure in United State. (2) Value in parentheses is number of lagged first differences included in Dickey-Fuller regression.
Source: own calculations

The table indicates that for all cases, a unit root in the series cannot be rejected at the 5% level of significance. Furthermore, the conclusion that all series contain a unit root is invariant to the inclusion of only an intercept in the Dickey-Fuller regression or the inclusion of both an intercept and a time trend in the Dickey-Fuller regression. These results imply that there is strong support for empirical implication (1) for both Central and Western Canadian agriculture.

Table 2 provides results of variable addition tests (Park (1992)) for Western and Central Canadian agriculture. This test is based on the Park (1990) canonical cointegrating regression (CCR) estimator of model parameters. Two CCR model specifications are estimated. The first includes both the $\ln(P_M/P_L)$ and $\ln(P_F/P_A)$ in the CCR specification of the ln(M/L) and ln(F/A) equations (the specification given in equations (3) and (4)). The second does not include $\ln(P_F/P_A)$ in the ln(M/L) equation and does not include $\ln(P_F/P_A)$ in the ln(F/A) equation (the specification given in equations (1) and (2)) .

Table 2: Park (1992) Variable Addition test for cointegration for Western and Central Canadian Agriculture (1958-2006)

Superfluous Regressors	Central Canada			
	without other price		with other price	
	M/L	F/A	M/L	F/A
t^2	0.680	0.300	0.089	0.811
	(0.40)	(0.58)	(0.77)	(0.37)
t^2t^3	8.390	1.930	6.720	1.460
	(0.015)	(0.37)	(0.035)	(0.48)
$t^2t^3t^4$	9.440	4.700	6.750	2.560
	(0.024)	(0.19)	(0.080)	(0.46)
	Western Canada			
	without other price		with other price	
	M/L	F/A	M/L	F/A
t^2	0.33	0.069	1.33	0.056
	(0.56)	(0.79)	(0.66)	(0.81)
t^2t^3	0.36	1.33	4.04	0.424
	(0.83)	(0.51)	(0.13)	(0.81)
$t^2t^3t^4$	1.22	1.51	5.12	1.73
	(0.75)	(0.68)	(0.16)	(0.62)

Note: Value in parentheses is probability value.
Source: own calculations

Strictly speaking, as equation (1) and (2) indicate, only own price (and not other price) should be included. However, other authors (e.g. Thirtle et al. (2002) and Liu and Shumway (2009)) undertake tests for cointegration with both prices included in the long run specification of the factor ratios.

The table indicates that cointegration cannot be rejected for either the ln(M/L) equation or the ln(F/A) for either Central or Western Canadian agriculture when all prices are included in the long run specification of the model. A conclusion of cointegration among variables is reached for Western Canadian agriculture when other price is dropped from the cointegrating regression. For Central Canada, cointegration is rejected for the ln(M/L) equation when other price is dropped from the CCR and is not rejected for the ln(F/A) equation. These results indicate that Western Canadian agriculture is consistent with empirical implication (2) but there is evidence against implication (2) for Central Canada, particularly for the ln(M/L) equation when other prices is dropped for the CCR specification.

Table 3 presents results of imposing two types of restrictions on the long-run specification of the ln(M/L) and ln(F/A) for Central and Western Canadian agriculture using the maximum likelihood estimator of Johansen (1991) with structural modelling approach developed by Pesaran and Shin (2002). Tests using lag lengths of two, three, four and five are presented (the Schwartz criterion minimized at lag length five for both regions, based on an unrestricted vector autoregression).

Table 3: Restricted maximum likelihood estimates of two stage CES parameters.

	Central Canada		Western Canada			
	Lag length=2		Lag length=3		Lag length=5	
Natural log of	M/L	F/A	M/L	F/A	M/L	F/A
Intercept	1.03	-1.38	0.906	-1.79	0.876	-1.854
Trend	-0.025	0.031	-0.021	0.041	-0.02	0.045
Natural log of P_M/P_L	-1.11		-1.197		-1.211	
Natural log of P_F/P_A		-0.80		-1.059		-1.042
Natural log of RES_C	0.11	-0.20	0.197	0.059	0.211	0.042
Natural log of RES_{US}	0.11	-0.20	0.197	0.059	0.211	0.042

Source: own calculations

Both of these tests assume there are two cointegrating relationships for input ratios both regions. Given the results of the previous table, this may not be a plausible conclusion for Central Canadian agriculture, especially for long run movements in the Machinery/Labour factor ratio. The first is a test that US research expenditures do not affect factor ratios for either region. The second is a test that all of the restrictions implied by the choice of the two stage CES given by equations (5) and (6).

The table indicates that the hypothesis that US research expenditures do not affect Canadian factor price ratios is rejected at the 5% level of significance at all lag lengths for Western Canadian agriculture and at all lag lengths except lag length two for Central Canada. Based on these results, we find evidence in support of empirical implication 6 in these data, or that US research expenditures are found to be important in the explanation of the long run movements of factor input ratios for Central and, especially for, Western Canadian agriculture.

The second part of the table presents tests of restrictions implied by the choice of the two stage CES function. Here the restrictions implied by the two stage CES function are not rejected for lag length two for Central Canadian agriculture and for lag lengths three and five for Western Canadian agriculture. Given that the Schwartz criterion minimizes at lag length five for both regions, the results of the tests seems most plausible for Western Canadian agriculture. Therefore, empirical implication 7 seems finds the most support in Western Canadian agriculture.

Table 4 presents the results of maximum likelihood estimates of parameters imposing the restrictions implied by the two stage CES function when likelihood ratio tests are not rejected from table (3) (i.e. lag length two for Central Canadian agriculture and lag length three and five for Western Canadian agriculture). From these results, implication (3), that of negative correlation between factor input ratios and own factor prices can be examined.

Table 4: Likelihood ratio tests of long run CES parameters.

Lag-Length	Central Canada		Western Canada	
	US Expenditures=0	CES	US Expenditures=0	CES
2	6.25	12.00	12.16	36.85
	(0.04)	(0.06)	(0.00)	(0.00)
3	27.40	26.68	15.72	1.77
	(0.00)	(0.00)	(0.00)	(0.94)
4	21.30	27.40	80.12	31.57
	(0.00)	(0.00)	(0.00)	(0.00)
5	108.17	57.09	43.00	5.41
	(0.00)	(0.00)	(0.00)	(0.49)

Note: Value in parentheses is probability value.
Source: own calculations

The table indicates that parameter elasticity estimates are consistent with the IIH for both regions because in all cases the own price coefficient is negative. For Central Canadian agriculture, the estimated long-run elasticity of substitution between machinery and labour is 1.11 and for fertilizer and land 0.80. The long run elasticity for research expenditures is 0.11 for the machinery/labour factor ratio and -0.20 for the fertilizer/land factor ratio. For Western Canadian agriculture, there is very little difference of elasticity estimates between the lag length three and lag length five estimates. The elasticity of substitution between machinery labour is 1.197 for lag length three and 1.21 for lag length five and the elasticity of substitution between fertilizer and land is 1.059 for lag length three and 1.042 for lag length five. The corresponding lag length three and lag length five elasticities for research expenditures for the machinery/labour factor ratio is 0.197 and 0.211 respectively and for the fertilizer/land factor ratio is 0.059 and 0.042 respectively.

The final set of results that will be presented relate to implication 5, that causality runs from input prices to quantities and not from input quantities to prices and empirical implication 7, that causality runs from prices to research expenditures. These implications are tested using Granger (1969) tests based on an unrestricted vector autoregression with a lag length of five (based on the minimization of the Schwartz criterion). These results are presented in table 6.

Table 5: Granger Causality Results.

Region	Result	F Statistic	Probability Value
Western Canada	P Granger Causes Q	2.14	0.008
	Q Granger Causes P	1.08	0.032
	P Granger Cause Research Expenditures	1.27	0.21
Central Canada	P Granger Causes Q	1.92	0.021
	Q Granger Causes P	1.43	0.13
	P Granger Causes Research Expenditures	1.44	0.18

Source: own calculations

Table 5 indicates that empirical implication 5, that causality runs from price ratios to input quantity ratios but not from input quantity ratios to input price ratios, is supported in the data from Central Canadian agriculture and mildly supported for Western Canadian agriculture. The hypothesis that price do not Granger cause quantities is rejected at the 1% level of significance for Western Canada and the 5% level of significance for Central Canada. In contrast, the hypothesis that quantities do not Granger cause prices is not rejected for Central Canada at the 10% level of significance but only the 1% level of significance for Western Canada

Granger causality tests for factor price to research expenditures are not supported by the data in either region. For Central Canada, the hypothesis that prices do not Granger cause research expenditures is not rejected to the 10% level of significance for both Central Canadian agriculture and Western Canadian agriculture.

4 Conclusion

Our results are summarized below:

Empirical Implication	Central Canada	Western Canada
All variables in the system are balanced. Assuming the variables in model are integrated, then this implies that the variables are I(1)	Cannot reject	Cannot reject
There are two cointegrating vectors given the stochastic variables in the system. There is one cointegrating vector for the machinery/labour equation and one cointegrating vector for the fertilizer/land equation	Cannot reject when all prices included Reject when other price is dropped	Cannot reject when all prices included Cannot reject when other price is dropped
Factor prices and quantities are negatively correlated over the long run	Cannot reject	Cannot reject
Current factor prices do not completely explain factor substitution	Not tested directly	Not tested directly
Causality runs from prices to quantities but not quantities to prices	Cannot reject	Cannot reject
CES specification holds	Cannot reject for lag 2 If fix at 5, then reject	Cannot reject for lag 3 and 5 If fix at 5, cannot reject
Research expenditures in US do not spillover to Canada	Cannot reject for lag length 2 Reject for all other lag lengths	Reject for all lag lengths
Prices cause research expenditures	Cannot reject at all lag lengths except length 2	Cannot reject at all lag lengths

We conclude that there is broadly consistent support for the induced innovations hypothesis for Canadian agriculture, especially for Western Canadian Agriculture. This is consistent with Karagiannis and Furtan (1990) for Canadian Agriculture and Thirtle et al. (2002) for US agriculture, but not with a more recent study by Liu and Schmway (2009) on US Agriculture. In addition, there is support for the notion the US as well as Canadian research expenditures are important to the explanation of input ratio movements in Canadian Agriculture in the long run. This could indicate the existence of spillover effects that run from US agricultural research to Canadian Agriculture.

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