The Exchange Rate and U.S./Canadian Relative Agricultural Prices

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ABSTRACT

The law of one price (LOP) plays an important role as a building block in theories of international trade and exchange rate determination. It also serves as a measure of integration for international commodity markets. The LOP states that in competitive markets after adjustment for transportation costs and trade barriers, identical commodities sold in different countries should sell for the same price when their prices are defined in a common currency.

The existing economic literature provides a vast body of theoretical and empirical investigations of the validity of the LOP. In general, previous evidence is mixed and there is no unanimous LOP support or refutation. The effects of exchange rate changes on agricultural outputs have been extensively studied, but the issue of the impacts on traded non-farm produced inputs has not been explored as much.

This study investigates the impact of the exchange rate ($CN/$US) on the relative prices in U.S. and Canadian agricultural markets for five major farm outputs and four non-farm produced inputs, which are traded between these two closely integrated economies. Adherence to the LOP is evaluated by examining the pass-through effects of exchange rate changes on these prices using quarterly data. The sample covers the period of 1975 – 1999, when there were substantial exchange rate movements. Regression and cointegration techniques are utilized to estimate whether and at what rate exchange rate changes are transmitted to prices. The empirical results give rise to supportive evidence in favor of the LOP for the five farm outputs. The evidence is somewhat weaker for three of the four non-farm produced inputs, and the LOP is violated for one input.

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TO MY DEAREST PARENTS, MY BROTHER AND MY HUSBAND

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Chapter I – Introduction

1.1 Problem Statement

This study investigates the impact of the Canadian dollar/U.S. dollar ($CN/$US) exchange rate on the relative prices in the U.S. and Canadian agriculture. Econometric models are estimated to examine the dynamic effects of exchange rate fluctuations during 1975 – 1999 on agricultural output and traded non-farm produced input prices. The law of one price (hereafter LOP) validity is investigated by examining the pass-through effects of the exchange rate changes on agricultural prices.

With the move away from the Bretton Woods system of fixed exchange rates and emergence of a well-integrated international capital market, it has become increasingly important to analyze the impact of macroeconomic variables on agricultural markets. Schuh's 1974 paper on exchange rate impacts on the agricultural economy opened up a new area of research into the link between the macroeconomy and agriculture. In his pioneering work, Schuh made the fundamental argument that the exchange rate was an omitted variable in economic analysis of the U.S. farm sector and emphasized its effect on the prices received for farm products. Since then, macroeconomic-agricultural linkages have been the objective of much research and the importance of macroeconomic factors for agriculture has been well recognized. Because the exchange rate is a crucial transmission mechanism by which macroeconomic factors bear on agricultural trade, and thus on agriculture overall, many recent empirical studies have focused directly on measuring these impacts. Yet, despite the recognition that the exchange rate has important effects on agricultural performance, economists still argue about the degree of these effects.

To further investigate macroeconomic–agricultural linkages, this study will concentrate on exchange rate effects on the U.S. and Canadian agricultural prices, in particular attempting to estimate the magnitude of those impacts. The analysis is conducted in a framework constructed by Carter, Gray and Furtan in an earlier article in 1990, which evaluated exchange rate effects on both tradable inputs and outputs in Canadian agriculture. The study rebuilds Carter *et al.*'s model, then extends their analysis by adding eleven years to the data sample and incorporating various lag lengths in model specifications. Thus the pass-through effects of exchange rate changes are estimated within this longer time period for agricultural output and non-farm produced input prices, attempting to examine the LOP validity and investigate the consistency of Carter *et al.*'s findings in this new sample period. Modern econometric techniques are also applied to test the robustness of the original results.

The exchange rate is a key macroeconomic force that influences the prosperity of the U.S. and Canadian agriculture. Its movements are an important source of risk to farmers and ranchers, both in production and trade. Prices of traded non-farm produced inputs make up an important part of production costs and represent a major concern for farmers. Trade in many important agricultural inputs across the Canadian/U.S. border is relatively free of barriers. For example, fertilizer, machinery and refined petroleum products move between the two countries duty free. The prices of most inputs imported from the U.S. and used in Canadian agricultural production are normally determined in the large U.S. market. As a result, the $CN/$US exchange rate has an important bearing on Canadian input prices. Although the effects of exchange rate changes on agricultural outputs have been extensively studied, the adjustment of agricultural input prices to exchange rate changes has not received as much attention. Exchange rate fluctuations are often difficult to predict; however, an understanding of their impacts will help agricultural producers anticipate the consequences of exchange rate changes and take appropriate actions in production and trade decisions.

1.1.1 The Nominal Exchange Rate and the Real Exchange Rate

The exchange rate in nominal terms is the value of the currency of one country against the currencies of other countries, in particular, the nominal $CN/$US is the value of the Canadian dollar against the U.S. dollar. It is affected by supply and demand for Canadian dollars in international currency markets. Interest rates, inflation rates, trade balances and investors' expectations are the main factors influencing the supply and demand conditions, hence fluctuations of the exchange rate. Among other things, the nominal exchange rate helps determine how much is paid for imported goods and services and how much is received for exports.

The exchange rate in real terms is defined by the nominal exchange rate and nominal price levels. In short, the real exchange rate is the nominal exchange rate adjusted with inflation. The real \$CN/\$US exchange rate can be expressed as

$$q_{\$CN/\$US} = e_{\$CN/\$US} * P_{US} / P_C, \qquad (1.1)$$

where q is the real \$CN/\$US exchange rate, e is the nominal exchange rate, P_C and P_{US} are the price levels measured in Canadian dollars and U.S. dollars, respectively. The real exchange rate is the relative price of two output baskets, in other words, the price of expenditure baskets containing the typical purchases of Canadian households and firms and those of their U.S. counterparts. A real depreciation (appreciation) of the Canadian dollar against the U.S. dollar occurs when the Canadian dollar's purchasing power over the U.S. goods and services falls (rises) relative to its purchasing power over Canadian goods and services. A nominal depreciation (appreciation) implies a real depreciation (appreciation) if the output price indices are unchanged, but often prices and the exchange rate are changing simultaneously. The real exchange rate is important for quantifying deviations from purchasing power parity (PPP) and analyzing macroeconomic demand and supply conditions in open economies.

The theory of purchasing power parity is an integral part of international economics. PPP states that the exchange rate between two countries' currencies equals the ratio of the countries' price levels. The basic premise of the PPP theory is that the power of a currency to purchase goods and services is related to price level movements. The implication of the PPP hypothesis is that changes in price levels cause proportional changes in nominal exchange rates. Further, conformity to PPP implies that the real exchange rate is a constant. It predicts that a fall (rise) in a currency's domestic purchasing power as indicated by an increase (decrease) in the domestic price level will be associated with a proportional currency depreciation (appreciation) in the foreign exchange market.

Exchange rate pass-through is another important concept. Pass-through refers to the degree to which exchange rate changes are reflected in destination currency prices of traded goods. If the foreign seller adjusts his home currency price to fully offset the exchange rate change, then pass-through is zero. On the other hand, if he does nothing to his home currency price, then the exchange rate change is fully reflected in the foreign or destination currency price and pass-through is one. Finally, if he adjusts his home currency price to offset only part of the exchange rate change, then pass-through is greater than 0 but less than 1, or pass-through is incomplete. A depreciation of the Canadian dollar against the U.S. dollar is expected to increase the prices of imports and exports measured in the Canadian dollar. This relationship between these two currency prices is defined as the exchange rate pass-through.

1.1.2 Canadian Agricultural Development and its Dependence on Trade

With the rise of Canada's industrial and services sectors, agriculture, once central to the Canadian economy, now account for less than 2% of the country's GDP and employs about 3% of the labor force. Nevertheless, agricultural exports, such as wheat, remain an important source of export earnings. Canada is the world's second largest wheat exporter and a major producer of barley, rapeseed and oats. The Canadian prairies are especially renowned for the quality of the wheat they produce. In a typical year about 75% of Canada's wheat is exported, although this figure fluctuates sharply from year to year depending upon harvests around the world. Oats and barley are also important crops in the prairie provinces, while corn (maize) is the principal crop of Ontario. The canola (oilseed rape) harvest grew substantially in the 1990s and is now challenging wheat as the largest source of farm income among all crops. Fruit, vegetables and tobacco are grown mainly in Ontario, the province with the largest total farm income. Livestock is an important source of farm revenue. Around 40% of livestock revenue comes from cattle sales.[1]

Given the relatively small size of Canada's domestic market, the external trade sector has always played a significant role in the growth of the Canadian economy, particularly in the growth of Canadian agriculture. Indeed, external trade was the main contributor to the country's early economic development, as Canadian wealth was largely built on the exploitation and export of the country's vast natural resources, which, in return, brought in substantial inflows of capital. Currently more than 40% of the country's total output is exported and although the primary sector continues to make a significant contribution, secondary goods now account for over 70% of Canada's

[1] See Country Profile 2000: Canada p.29-30.

shipments abroad. More than one-third of all Canadian jobs are dependent upon the export sector.

The trade volumes of Canadian agricultural and fish products in 1999 are shown as in table 1-1. Primary goods, including agriculture products, accounted for 26% of Canadian merchandise exports but less than 10% of its merchandise imports in 1999. One of the most significant effects of free-trade agreements with the U.S. has been the steady rise of secondary goods as a share of total exports, as greater economic integration stimulates sales of industrial goods, machinery and equipment and consumer goods. Although exports of secondary products have grown sharply over the last ten years and now account for 75% of total merchandise exports, they are still outweighed by imports of secondary goods.

For most of the second half of the 1990s the impetus for Canada's economic growth came from solid export growth, stemming in particular from rising demand for Canadian products in the United States. The surge in export growth that followed the implementations of the free-trade agreement with the U.S. in 1989 and then North American Free Trade Agreements in 1994 pushed the share of exports of goods and services as a percentage of GDP up from 25% in 1990 to 41% in 1999.[2]

Table 1-1. Canadian Goods Exports & Imports in 1999

($CN million; balance-of-payments basis; including re-exports)

	Goods exports	Goods imports
Agricultural & fish products	25,614	17,639
Energy products	30,310	10,646
Forestry products	38,903	2,741
Industrial goods & materials	56,940	62,142
Machinery & equipment	84,959	108,230
Automobile products	96,142	75,903
Consumer goods	13,591	36,962
Total including others	360,600	326,662

Source: The Economist Intelligence Unit (EIU), *Country Profile 2000: Canada p.35*.

[2] Country Profile 2000: Canada p.33-34.

1.1.3 Bilateral Trade Development between Canada and the U.S.

Canada's trade position is largely determined by its proximity to the United States. For most of the 20th century Canada ran a current-account deficit with the U.S., as revenues from exports of primary goods were exceeded by spending on imports of manufactured and capital goods. Since the early 1980s, however, Canada has recorded growing merchandise trade surpluses with the U.S., by increasing its exports of secondary goods without reducing its shipments of traditional primary commodities.

Canada's close trade relations with the U.S. were strengthened when the bilateral Free Trade Agreement (FTA) came into effect on January 1, 1989. Tripartite negotiations with Mexico led to the implementation of the North American Free Trade Agreement (NAFTA) on January 1, 1994.

The United States is the most important trading partner of Canada, as shown in table 1-2. In 1999, 85.9% of all Canadian exports were shipped to the U.S., while the U.S. supplied 76.3% of Canadian merchandise imports. The value of trade between the two countries has risen continuously since the implementation of the FTA in 1989, growing at an average annual rate of 10.5% in nominal Canadian dollar terms. The total value of goods shipped in both directions reached $CN 559 billion in 1999, up from $CN 504 billion in the previous year. This amounts to the largest trade flow in the world between any two countries. The U.S. imports more from Canada than from anywhere else. The merchandise trade surplus recorded with the U.S. nearly doubled in 1999, reaching a record of $CN 60.5 billion.[3]

This brief summary of the Canadian agricultural and trade development illustrates that Canada is a major commodity producer and exporter. It has high degree of capital mobility, especially with the United States. The large trade volume between Canada and the United States makes the $CN/$US exchange rate a very important factor in Canadian agricultural production and trade.

[3] See Country Profile 2000: Canada p.34-35.

Table 1-2. Main Trading Partners of Canada in 1999

($CN million)

	Exports to	Imports from
US	309,663	249,173
Japan	9,211	10,591
UK	5,331	7,707
Other EU	12,874	20,818
Other OECD	7,156	13,208
Other countries	16,365	25,168
Total	360,600	326,662

Source: The Economist Intelligence Unit (EIU), *Country Profile 2000: Canada p.35*.

1.1.4 The Development of the Canadian Dollar against the U.S. Dollar

As the U.S. plays such a crucial role in Canada's foreign trade and foreign investment flows, the $CN/$US exchange rate is not only a key policy concern for the U.S. and Canadian governments, but an important risk concern for commodity producers and exporters in the two countries as well. The development of the Canadian dollar against the U.S. dollar after the breakdown of Bretton Woods system can be considered as falling into three periods, as shown in figure 1-1.

(1) 1973 – 1986: A period of continuing depreciation

After appreciating slightly in 1976, the Canadian dollar continued to fall until 1986, partly due to a sustained appreciation of the U.S. dollar against all the major currencies beginning in 1980. Canadian and U.S. inflation rates were similar until 1981, as shown in figure 1-2. The nominal exchange rate and the real exchange rate stayed close together except during a short period from 1977 to 1979, when the nominal exchange rate depreciated more than the real exchange rate. After 1981, the nominal exchange rate rose more rapidly than the real exchange rate and their differential reached a maximum in 1986. Also Canadian inflation began to exceed U.S. inflation in 1981 and the differential was partly offset by nominal depreciation of the Canadian dollar. As a result, the real exchange rate remained nearly unchanged until 1984. Other factors resulting in the weakness of the Canadian dollar include, most importantly, weakness in commodity prices and periodic concern about anti-inflationary policy.

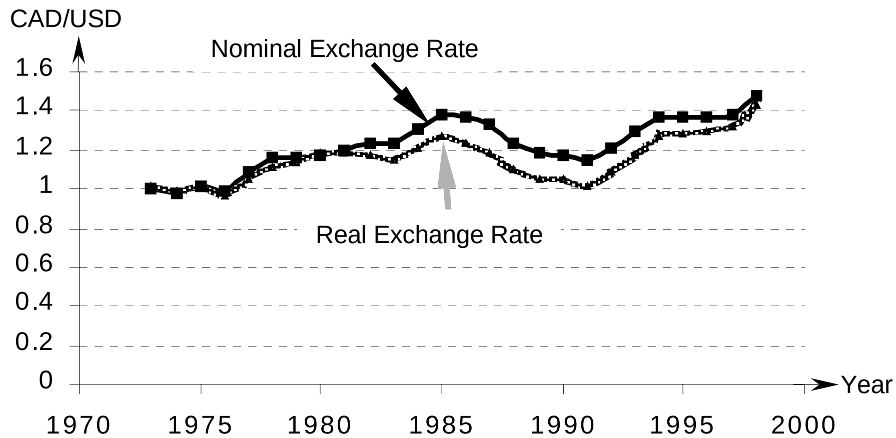

Figure 1-1. The nominal and the real exchange rates between Canada and the U.S.

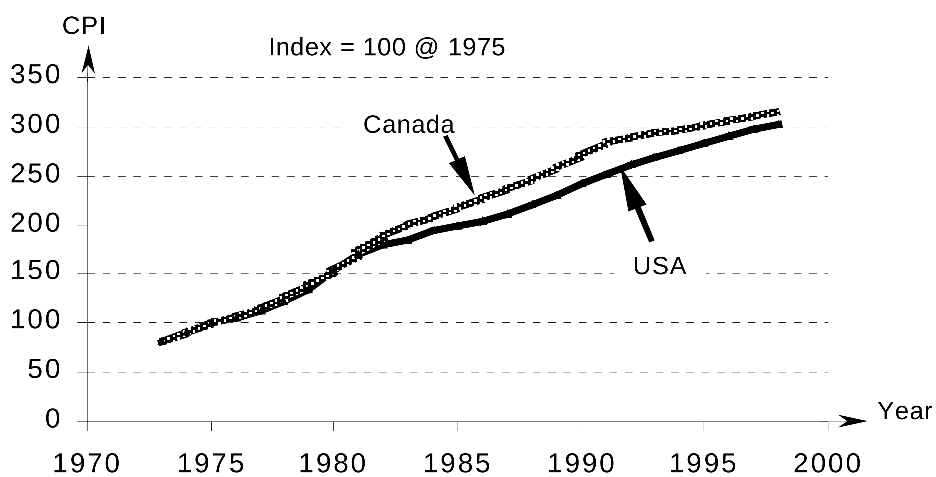

Figure 1-2. The consumer price indices of Canada and the U.S.

(2) 1986 – 1991: A period of continuing appreciation

With the U.S. dollar generally weakening against all the major currencies to its pre-1980 level in foreign exchange markets, the Canadian dollar moved parallel with other currencies and began a modest recovery against the U.S. dollar in late 1986. The exchange rate reached a cyclical peak of appreciation in 1991. The government's policy of maintaining a real interest rate differential with the U.S. kept the currency generally strong against the U.S. dollar during the late 1980s and early 1990s. During this period, the nominal and real exchange rates both gradually appreciated at roughly the same pace. The strength of the Canadian dollar was boosted by various factors including a buoyant Canadian economy, sharply higher interest rates, solid commodity prices, expansionary fiscal policy and a significant tightening of monetary policy.

(3) 1991 – Present: A period of gradual and sustained depreciation

An easing of monetary policy in 1992-93 led to the interest rate differential with the U.S. being eroded. Consequently, the Canadian dollar began depreciating sharply in 1992, followed by a gradual, but sustained weakening in parallel with the lowering of interest rates through 1994. It re–established a degree of stability though 1995 and 1996. From 1995 to late 1998, the U.S. dollar experienced its largest appreciation against all the major currencies since the first half of the 1980s, resulting in a weakened Canadian dollar again until 1998. The differential between the nominal exchange rate and the real counterpart became smaller. The nominal exchange rate appreciated a little in 1996, however, the real exchange rate kept depreciating slowly. The depreciation of the Canadian dollar could be attributed to low interest rates, significant unused capacity in the economy, softening commodity prices and unfavorable international environment.

1.2 Objectives of the Study

The main objective of this study is to analyze the linkage between the $CN/$US exchange rate and prices of agricultural outputs and traded non-farm produced inputs in two close and integrated economies: the U.S. and Canada. Effects of the exchange rate movements on agricultural prices are investigated by testing the LOP validity. Particular objectives include the following:

1. To estimate the exchange rate pass-through on the relative prices of agricultural outputs, in particular wheat, soybeans, corn, feeder steers, and slaughter steers.
2. To assess the exchange rate pass-through on the relative prices of major traded variable farm inputs used in production, particularly fertilizer, pesticides, petroleum, and farm machinery.

1.3 Methods and Hypotheses

This study tests the assumption that perfect commodity arbitrage exists in the trade between the U.S. and Canada. This assumption is based on the notion of free trade and perfect competition. It also assumes that some inputs to agricultural sector come from the traded sector. Thus the exchange rate movements affect not only the agricultural output prices, but those of the traded inputs as well. In an examination of the pass-through of changes in the $CN/$US exchange rate, Carter *et al.* stated that the data from 1975 to 1988 are consistent with the hypothesis of a complete pass-through of exchange rates for many important variable inputs to agriculture production. Some prices he studied showed a lagged adjustment period to the exchange rate changes (Carter, Gray and Furtan 1990). This study re-tests the hypothesis of a perfect exchange rate pass-through on agriculture prices, in the presence of good market arbitrage between the U.S. and Canada. The specific hypotheses relating to the objectives are as follows:

1. Within a short period, such as one quarter, there is a full exchange rate pass-through on prices of agricultural outputs.
2. Within a short period, there is a complete exchange rate pass-through on prices of traded non-farm produced inputs.
3. The lagged adjustment time of traded non-farm produced input prices to the exchange rate pass-through is longer than that of output prices.

1.4 Methodology

The estimation of the exchange rate pass-through is based on the theory of the law of one price, which states that, in the long run, traded commodity prices in two countries must be the same, once the transaction cost is taken into account. If commodity arbitrage is relatively effective the LOP should hold. The implications of the Canada-

U.S. exchange rate on the performance of the agriculture sectors are analyzed within the same framework developed by Carter, Gray and Furtan (1990) with an extended time period of eleven years (1989-99) during which there have been substantial exchange rate movements. The analytical formulation embraces the idea that changes in agricultural performance occur as a response to changes in the economic environment, in particular, the exchange rate.

Carter *et al*. examined the exchange rate pass-though on small specific output industries in a model of partial equilibrium analysis, where Canada and the U.S. are the exporter and importer, respectively. They assume both countries affect world prices as large countries. Carter *et al.* adopted a dichotomy of which goods in the economy are aggregated into tradables and non-tradables. A change in exchange rates may result in a fluctuation in the nominal and real prices of the tradables, thus the production in each sector. Since inputs may also be traded, the LOP implies a change in the exchange rate would cause changes in cost of exporting production and thus export prices and trade volumes between the two countries. The magnitude of the net change in prices and trade depends upon the elasticity of excess demand and supply and proportion of traded inputs in total cost of production. (Carter, Gray and Furtan 1990)

The theoretical framework in which to analyze the exchange rate effects on prices and production is shown in figure 1-3. It assumes that international trade of inputs in agricultural production occurs between Canada and the U.S. In Canadian agricultural market, it is hypothesized that output prices respond quickly to the exchange rate movements within a short period, such as a quarter; while traded non-farm produced input prices show sluggishness in price adjusting process in the short run. Initially the price of good *i* expressed in the Canadian dollar is OP_1 and production volume is equal to OQ_1. If a change in the exchange rate $CN/$US causes the value of the Canadian dollar to depreciate, this results in an immediate increase in the output price by an amount equal to P_1P_2 as well as an expansion of production by an amount equal to Q_1Q_2. Supply amount moves from original point A to point B. No changes of traded-input prices occur within this short time due to the lagged effect. Point B also applies to a case when all inputs are non-tradable and hence there is no pass-through on input prices. In the long run, the currency depreciation eventually will increase traded non-farm produced input prices and thus cost of production. Production volume therefore reduces.

In an extreme case of all inputs are traded, the supply curve would shift backward from $S_1$to S_2 as a response to the devalued currency. This shrink effect in production offsets the expansion effect due to output price increases, resulting in an unchanged production volume OQ_1. Point C in figure 1-3 is of complete exchange rate pass-through on both input and output prices. It is noted that S_1 may not shift all the way back to S_2, since not all inputs are traded or perfect exchange rate pass-through may not occur. The supply curve would shift somewhere between S_1 and S_2, the net change in production of good *i* is decided by a combination of factors including the elasticity of the supply curve S_1, the percentage of traded inputs in total production costs and responses to exchange rate changes in their prices.

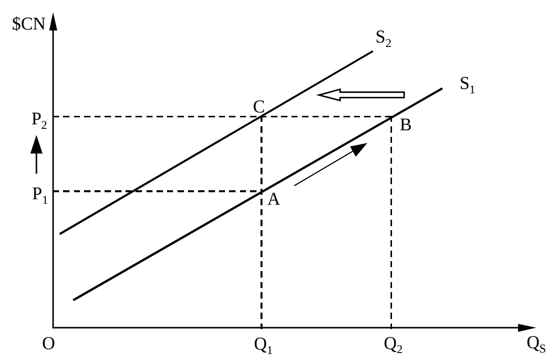

Figure 1-3. Effects of an exchange rate depreciation

The econometric model constructed in Carter *et al*'s paper to estimate the exchange rate pass-through effects are rebuilt in this study. Carter *et al*'s basic model for estimating the exchange rate pass-through on prices is of the form:

$$Log(P_t^c / P_t^u) - Log(P_{t-1}^c / P_{t-1}^u) = C + \beta_0 * Log(E_t / E_{t-1}) + \beta_1 * Log(E_{t-1} / E_{t-2})$$
$$+ \beta_2 * Log(E_{t-2} / E_{t-3}) + \varepsilon_t \qquad (1.2)$$

where

P_t^c = the Canadian dollar price of the commodity at time period *t*

P_t^u = the U.S. dollar price of the commodity at time period *t*

P_{t-1}^{c} = the Canadian dollar price of the commodity at time period (*t-1)*

P_{t-1}^{u} = the U.S. dollar price of the commodity at time period (*t-1)*

C = the intercept term

E = the exchange rate of \$CN/\$US

β_0 = the contemporaneous coefficient

β_1 = the exchange rate pass-through effect lagged one quarter

β_2 = the exchange rate pass-through effect lagged two quarters

ε_t = the residual term

Thus, the contemporaneous exchange rate pass-through is estimated by analyzing the parameters in equation (1.2), and the lagged effect of exchange rates on prices is also captured by adding lagged exchange rates to the regression analysis. (Carter, Gray and Furtan 1990)

1.5 Outline of the Study

Chapter 2 provides an introduction to the theory of the LOP, as the fundamental theory basis of this study. It also offers a general review of the existing literature on the LOP as well as several studies focusing on agricultural prices in the particular Canadian and U.S. agricultural trade markets. Chapter 3 contains an introduction to the econometric models and explains the econometric techniques used for modeling the data to analyze the exchange rate pass-through and test the LOP. A description of the data utilized in this study is provided. The graphical evidence of the LOP validity for agricultural prices of Canada and the U.S. are presented. The empirical analysis contains three parts. First, Carter *et al*'s original estimation results and our interpretation are described. Second, Carter *et al*'s analysis is extended using similar data for investigating the LOP validity in a short, intermediate, and medium run. Third, the concept of cointegration and its application to the LOP as a long-run equilibrium relationship is explained. Each of the series under study is tested for stationarity. Then tests for cointegration are conducted so as to examine the LOP in a long run. The corresponding empirical results are presented. Chapter 4 is a summary and conclusions chapter.

Chapter II - The Theory of the Law of One Price

2.1 Introduction to the LOP

There are two versions of the LOP, the "absolute" and "relative" version. The "absolute" or "short-run" version of the LOP asserts that the foreign price of a commodity, once adjusted for the exchange rate, will be equal to the domestic price of the commodity plus an adjustment for transportation costs and trade taxes. In other words, in competitive markets after adjusted for transportation costs and barriers to trade (such as tariffs), identical goods sold in different countries should sell for the same price when their prices are expressed in terms of the same currency. The LOP may be expressed as:

$$P_i = eP_i^* \quad (2.1)$$

where P_i is the domestic currency price of good i, P_i^* is the corresponding foreign currency price, and e is the exchange rate, defined as the home-currency price of foreign currency. Equation 2.1 implies that the price of a commodity, once converted to a common currency, is expected to be equal in two spatially segmented markets.

The "relative" or "weak" version of the LOP predicts the proportionate changes in the variables of equation 2.1, and can be regarded as the test of the LOP in the long run. Compared with the absolute version, the relative version of the LOP is less restrictive.

The principle of the LOP is based upon and reinforced by several theoretical mechanisms. One is commodity arbitrage, which is feasible only if different geographic locations are connected by linkages of trade. The profit opportunities foreseen by arbitragers motivate the price adjustment process. Price parity is established and maintained by the profit seeking actions of commodity traders and arbitragers across all the markets. Disparities that appear in prices at two trade locations may result in the physical transfer of commodities from the higher priced to the lower priced market, which is expected to narrow the price gap in the two markets. Accordingly, prices of individual traded goods that are close substitutes tend to converge and equalize. Existence of a high degree of substitutability in consumption and production is another theoretical mechanism enforcing price parity in international markets.

On the other hand, commodity arbitrage activities may be obstructed if transportation or other transaction costs are too high, the availability of substitutes is limited due to spatially dispersed markets and price setting power, or the movement of goods across country borders is constrained by trade barriers. All these factors might prevent or limit price convergence.

It's noted that the presence of non-tradable inputs of production embodied in traded goods is another factor contributing to price divergences.

The LOP is also extended to include price parity in a general basket of goods and services. In this form, the theory explaining price differences between markets is referred to as the Purchasing Power Parity (PPP) hypothesis. As a building block of the PPP hypothesis, the LOP contributes to predicting and judging whether a currency is overvalued or undervalued. The intuitive reasoning underlying the PPP hypothesis is that, if the LOP were to hold for every commodity, it should also hold for an aggregate of commodities. A distinction should be drawn between the theory of PPP and the LOP. In its most general form, PPP maintains that the exchange rate is proportional to the ratio of price levels in two countries. Under PPP, the price terms are aggregate price levels, and the exchange rate is determined simultaneously with price levels in each country. Under the LOP, the price terms p_i and p_i* are prices of specific commodities, and the exchange rate is exogenous.

In a simple one-good economic world, the LOP and PPP are synonyms. However, differences arise between the two theories in the real world of multiple good markets. Aizenman (1984) stated that, even in the extreme case where the LOP holds for each commodity, differences in consumption baskets across countries implies that changes in relative prices will result in deviations from PPP. It is further emphasized PPP may hold even when the LOP fails to hold for each individual commodity, since prices and exchange rates should not stray too far from the relation posited by the theory of PPP.

2.2 Transaction Costs

The fundamental mechanism underlying the LOP is that commodity arbitrage creates a link between the foreign and domestic prices of a commodity. If both markets are efficient, when price differential exceeds transaction costs, the arbitrage activity of traders is expected to ensure the eventual establishment of price parity between those geographically dispersed markets. It should be noted that the significance of the LOP lies in its implication that differences in the prices of commodities in different geographic locations linked by trade tend to dissipate rather than persist in the long run. However, it is not realistic to expect prices to show complete convergence in two markets. The reason is that the arbitrage activity of traders implies that long-run price differentials in traded commodities between different geographic trade locations is systematically related to transactions costs.

Transaction costs involves all expenses that occur during the process of shipping a commodity from one place to another, represented as the physical and monetary costs associated with transportation, storage, handling and processing, and delivery. Consequently, complete price parity in traded goods between two markets may be obstructed due to transportation and storage costs, delivery lags, interest forgone, insurance costs, rate of return to arbitragers, tariff and non-tariff barriers, and inefficiencies in the transmission of information.

Transaction costs may impede instantaneous adjustment of prices at spatially separate locations, thus contribute to the presence of short-run deviation from the LOP. An example of the empirical validation of this notion is provided in an analysis by Williams and Wright (1991), who examine the influence of the physical and monetary costs of storage on the price adjustment process. The authors conclude that transactions costs preclude contemporaneous adjustment in prices.

2.3 Importance of the LOP in Economics Theory

The LOP is an important principle in terms of trade theory: when trade is open and costless, identical goods must trade at the same relative prices regardless of where they are sold. The LOP provides one link between the domestic prices of goods and exchange rates. In a barter world, if transportation costs and trade impediments are abstracted from, the price of a commodity in terms of real goods must clearly be the same everywhere in the trading area, both nationally and internationally. More generally, there can be only one equilibrium set of barter terms of trade. If this were violated, traders could make unlimited and riskless profits by buying a commodity where it is relatively cheap and selling it where it is dear. These ideas are easily extended to consider the case of international trade between monetary economies. The implication is that domestic prices, once converted to common currency units, will be the same as international prices.

The LOP also shows up as an important ingredient in the 'monetarist' model of exchange rate determination. It contributes to explaining the transmission of inflation internationally, the insulation properties of exchange rates, and the consequences of government intervention. Thus, as Officer has commented: "the LOP for tradable commodities is an essential ingredient in the body of knowledge known as international economics. Without the imposition of this law, there would not even be the traditional 'pure theory' of international trade. Without this law, much of the 'monetary theory', too, would have to be reconstructed (Officer 1986, p. 159)".

Similar arguments can be found in Protopapadakis and Stoll (1983) and Baffes (1991). Baffes argued that modeling optimal intervention in a specific commodity market, domestic or international, requires a representative price which prevails at all markets. If an inappropriate price is used, policy recommendations based on such a model will not have the expected effects. Protopapadakis and Stoll stated that how well the LOP holds for commodities traded internationally is important for two reasons. First, some form of LOP is a necessary element in the monetary theory of exchange rate determination, which is based on a world economy in which deviations from LOP are not expected for any commodity. Second, study of the LOP is a tool to gain information on the efficiency and the degree of integration of international commodity markets.

The LOP serving as a measure of integration is especially important in international agricultural and food markets, where commodities are generally of a homogeneous nature across markets and thus are likely to conform to the conditions for price parity, especially for those that are highly traded. This view is expressed by Baulch (1997) who indicated that if prices are seen as the crucial policy prescription for agricultural development, then the presence of market integration is a vital precondition for development to be effective. Baulch posited that correct price signals will not be transmitted in markets that are not well integrated. This will result in the failure of farmers to specialize according to comparative advantage.

2.4 Review of the Literature

The economic literature includes a vast body of theoretical and empirical investigations of the validity of the LOP. Like all economic theories, the LOP can be expected to hold only to an approximate degree in the real world. But allowing for random errors as well as any systematic factors making for deviations from the law, the LOP should be expected to hold to a considerable degree. The issues addressed in various empirical investigations include examinations of the magnitude of the divergence of price differences in commodities from the equilibrium LOP. Some investigations are conducted on a disaggregated level by using commodity-specific data and price indices, while some other studies adopt an aggregative approach by using data commodity aggregate. In general, no unanimous support or objection as to the LOP is derived from these studies, some may find short-run violations of the LOP are often observed, some indicate that conformity is much more likely to occur in the long run.

Isard (1977) clarified two contexts in which the LOP is valid. First, the products of different countries are close to identical, or near-perfect substitutes, so that any price disparities would be rapidly eliminated by commodity arbitrage. He gave an example of a comparison of the United States, European, and Japanese prices of various well-defined steel items c.i.f. for delivery in a common port. Second, in the absence of restrictions on commodity arbitrage, a product of any single country sold competitively in two different markets (foreign or domestic) would also obey the LOP in the sense that its dollar-equivalent prices in the two markets could not differ by more than the cost of transportation between these markets (p.942).

A number of reasons are suggested for the invalidity of the LOP. Miljkovic (1999) outlined numerous possible factors that can distort price convergence in international trade. These factors include exchange rate risk, choice of currency denomination of export prices, and price responses to exchange rate changes; geographical separation of markets which leads to transportation costs, trade regionalization and other institutional factors, tariffs, and non-tariff barriers arising in the international trade of goods; and market specific pricing of exports due to differences in the export demand elasticities across destination markets.

Giovannini (1986) found that deviations from the LOP are due to exchange rate surprises, but also to price staggering and ex ante price discrimination. The stochastic properties of deviations from the LOP are crucially affected by the currency of denomination of export prices. Using data on domestic and dollar export prices of Japanese goods, he concluded that co-movements of prices of individual traded goods and the exchange rate depend not only on demand and cost parameters, but also on the stochastic process followed by the exchange rate.

Ardeni (1989) offered three reasons for the failure of the LOP. Institutional factors influence price settings in different markets, even for the same goods. And cost of arbitraging can be high, at least for short periods of time, especially for markets strongly influenced by international agreements. Additionally, errors in data, and in definitions of various prices may explain some of the violations of the LOP.

The LOP is concerned with a price adjustment process which brings about the validity of the law within a certain time period. Dornbusch (1976) created a model of exchange rate dynamics which explicitly focused on the differential behavior of prices in goods markets and asset markets. The model assumes that the domestic currency price of domestic goods adjusts slowly to a disturbance, but that the domestic currency price of foreign goods adjusts instantaneously to the exchange rate. In the model, the LOP is continuously maintained for imported goods, but deviations from PPP occur during adjustment dynamics, while PPP holds in the long-run equilibrium.

2.4.1 Testing the LOP by Regression and Cointegration Techniques

Various methods of testing the LOP are suggested in empirical studies. Baffes (1991, p.1264) summarized the traditional regression test procedure: once converted to common currency units by the exchange rate, a commodity price in one country is regressed on the same commodity's price in another country. Then, the slope coefficient is restricted to equal one and (possibly) the intercept term is restricted to equal zero. If such restrictions are not rejected, the conclusion is that the LOP holds. Isard (1977) and Richardson (1978) had adopted such procedures and derived unfavorable evidence as to the LOP. Crouhy-Veyrac *et al.* (1982) criticized those traditional tests by exploring the limits of those tests disregarding transfer costs of moving goods across national boundaries and pointed out that in the absence of evidence about these costs, any general verdict about the LOP would probably never be able to be derived. If those costs were taken into account, favorable results as to the LOP would be obtained.

Empirical investigations in the past two decades have developed new methods of testing the validity of the LOP and give rise to mixed results. Empirical support for the LOP is often evaluated in terms of the time taken for divergences from the LOP to dissipate. Faster rates of convergence to parity are indicative of evidence in favor of the price parity theory.

Protopapadakis and Stoll (1983) argued that in models where a distinction between traded and non-traded goods is made, such as in sophisticated models of the monetary theory of exchange rate determination, digression from the LOP are expected for non-traded goods, although not in response to all disturbances. They further argued that unanticipated monetary or fiscal changes, demand changes, or disturbances that originate in the exchange market will lead to relative price changes so that PPP will not hold when measured with broad price indices. Deviations will be systematic and relatively long lived, inducing balance of payments adjustments. In a later work, Protopapadakis and Stoll (1986) formulated a multi-equation model which made an explicit distinction between short-run and long-run prices. The results indicate that the short-run version of the LOP almost never holds but the LOP receives strong empirical support in the long run.

Goodwin *et al.* (1990) altered the analytical model by arguing that transaction costs should be explicitly incorporated. They used two distinct procedures to test the LOP. The first approach uses the generalized method of moments econometric procedure to estimate rationally formed expected future prices. Actual freight rates for wheat trade are utilized to provide a proxy measure of transactions costs. A second approach employs a nonparametric analysis of price parity using the actual freight rates for trade between several important wheat markets. They concluded that using a simple expectation-augmented model produces greater support for the LOP than the same model using contemporaneous prices.

Cointegration is another frequently used procedure for testing the LOP in recent years, including bivariate and multivariate. Cointegration means that although many developments can cause permanent changes in two or more time series, some long-run equilibrium relation exists that ties the series together, represented by their linear combination. Cointegration analysis provides a way to formalize the idea of co-movements among the prices of a same good in different countries. It allows for price adjustments in the short run while testing the LOP as a long-run equilibrium condition, serving as a tool to investigate the price adjustment process that characterizes spatial price relationships between markets. Tests for cointegration found their place immediately after being developed and became a very popular method in LOP studies. It was argued (Ardeni 1989, Goodwin 1992) that conventional regression tests of the LOP might have misrepresented or ignored the time-series properties of individual price data series. Such properties might have important implications for statistical tests of the LOP. In particular, ignoring serial correlation in an empirical test of the LOP can yield inferential biases and inconsistencies.

As an alternative, Ardeni and Baffes, among others, utilize the bivariate two-step cointegration testing techniques to verify the LOP as a long-run relationship. Ardeni (1989) challenged the stationarity properties of the exchange rate adjusted prices and found that in most cases the LOP does not hold. He concluded that deviations from the long-run equilibrium are permanent; commodity price arbitrage for the goods in his sample appears to be imperfect, and exchange rate movements are not fully transmitted to prices.

Baffes (1991) adopted the analytical method suggested by Ardeni, i.e., stationarity tests and subsequently a cointegration specification, and extended the model by paying special attention to transportation costs as a cause for the invalidity of the LOP. He studied seven commodities regarding four countries and derived supportive results for the LOP for the specific commodities and time periods examined. He concluded that the invalidity of the LOP in the long run arises for price-specific and time-period-specific cases rather than as a general failure.

However, Goodwin (1992) recognized that the bivariate cointegration tests are limited by the fact that cointegration considerations are confined to pairwise comparisons and some such tests require one of the two prices to be designated as exogenous. The multivariate approach suggests a maximum likelihood estimation procedure that provides estimates of all the cointegrating vectors existing among a group of variables. Thus, the multivariate cointegration tests may offer advantages over the bivariate two-step approach.

Doroodian *et al.* (1999) applied the multivariate cointegration testing procedure to five industrial countries: the United States, the United Kingdom, France, Japan and Germany. They examined adherence to the LOP in international markets under different exchange rate regimes and if a simultaneous relationship exists among prices of different countries. Monthly observations were used for the period 1957 to 1973 for the Bretton Woods system and the period 1973 to 1992 for the flexible exchange rate system. The findings showed that prices in industrial countries are related, as suggested by the monetary approach. Confirming the LOP, the results provided supportive evidence for PPP doctrine under the floating exchange rate system but not under the fixed exchange rate system.

Regarding cointegration as the methodology in LOP studies, Miljkovic (1990) stated that one should be very cautious when making inference on the basis of the results derived from cointegration testing. The practical importance of cointegration is not as a test for the LOP in its own right but as a pretest for other econometric tests for the LOP.

2.4.2 Testing the LOP by Commodity Type and Aggregation Level

Some studies investigate the validity of the LOP from the perspectives of different degrees of aggregation and types of commodities. In light of the aggregation level of the data used, these studies can be classified into two categories.

The first category is studies conducted on subcategories of general price indexes with an aggregative technique. For example, Officer (1986), employing a model making use of the tradable/nontradable goods dichotomy at an aggregate level, obtained results that offer strong support to the LOP for traded good at this aggregate level. Usually, this method tested the law domestically, hypothesizing that the prices of tradables and non-tradables are equal and, internationally, hypothesizing that the price of tradables is identical across countries.

In contrast to the conventional disaggregative testing of the LOP which usually exhibits unanimous results, the evidences of the aggregative approach for the LOP are strongly positive. Officer summarized that the aggregative technique is superior on three grounds: it theoretically accounts for cross-commodity substitution in production and consumption; it statistically avoids the difficult task of matching individual products across countries; and it econometrically commits no specification errors.

The second category contains studies utilizing data on basically homogeneous commodities. Studying individual products at this disaggregate level proves to be an important aspect in the LOP literature. Empirical evidence is mixed and conflicting.

Isard (1977) argued the LOP is denied as an empirical proposition in the context in which price data are at the most disaggregated product level and can be readily matched. Using annual data on four and five digit price indices for Canadian, German, and Japanese industrial goods and comparing their movements, he found the manufactured products of different countries exhibit relative price behavior which marks them as differentiated products, rather than near-perfect substitutes. As a result, it is impossible to assemble available data from this disaggregated level into aggregate price indices which can be expected to obey the LOP.

Crouhy-Veyrac *et al.* (1982), using price data at the finest possible level of disaggregation in official statistics, compared individual commodity prices between the United States and France at the eight digit level, and concluded on a more optimistic note that “all in all, the LOP emerges as a much less precarious, although a more qualified statement, than has been heretofore implied.” They pointed out that the LOP is increasingly accepted for primary goods, and it is premature to abandon the LOP for sophisticated manufactured products in the absence of evidence about transfer costs.

Protopapadakis and Stoll (1983) argued that since some empirical research on the behavior of various price indices casts doubt on the empirical validity of the LOP across countries for even the most disaggregated indices, identifying any commodities for which the LOP works satisfactorily is a necessity for models incorporating the LOP to be able to provide an adequate description of exchange rates. They tested the LOP for narrowly defined commodities traded in futures markets in different countries and found that deviations from the LOP are not highly correlated across commodities but arise from shocks in the individual commodity markets. The variability of the deviations from the LOP is found to diminish with maturity of the futures contract.

Ceglowski (1994) tested the LOP by analyzing the long-run behavior of a unique set of carefully matched, disaggregated export prices for manufactured goods from the United States, Germany, and Japan over the period 1974 - 90. His investigation of international prices at the microeconomic level provided little evidence of a long-run linear relationship between global prices of similar export goods from different sources, casting doubts on the empirical relevance of the LOP.

In recent studies, more attention has been directed to specific investigations of the LOP in agriculture, utilizing prices of basic homogeneous products. A common belief has existed among economists for a very long period of time that some agricultural commodities which are highly traded, such as grains, do follow the LOP. Empirical studies from recent years use various methods and get mixed evidences which do not support unanimously the LOP hypothesis.

Goodwin *et al.* (1990) tested the LOP for a number of oilseed products, wheat varieties, corn and sorghum monthly prices over a period of 72 to 128 months. The analysis included various export markets in the U.S. and Japanese and Rotterdam import markets. Only three out of seventeen commodity/market pairs that were analyzed violate the LOP. Thus, the LOP appears quite strong in international markets for the U.S. agricultural products.

Goodwin (1992) evaluated the LOP for prices in five international wheat markets: Canada, the United States, Australia, Rotterdam and Japan. Monthly wheat price data cover the period from January 1978 to December 1989. The results of his analysis indicated that the LOP fails as a long-run equilibrium relationship when transportation costs are ignored. However, when wheat prices are adjusted for freight rates, the LOP is fully supported.

Baharumshah *et al.* (1993) examined the validity of the LOP as a long-run relationship at the disaggregated level for the agricultural exports of a small open economy: Malaysia. The four major trading agricultural products under study are rubber, palm oil, cocoa and timber with monthly data covering the period 1985 - 92. The empirical results indicated the exchange rate pass-through on major agricultural exports to be less than complete and the LOP is invalid in the long run.

Kuiper *et al.* (1999) evaluated the LOP as a long-run equilibrium condition for a network of six important corn markets in the south of Benin by cointegration analysis within a spatial price error-correction model. The findings revealed the LOP holds in the long run. They further investigated the spatial market arbitrage and analyzed the short-run price dynamics. Two rural markets which quote the reference price are the fastest to adjust towards the permanent change induced by the common stochastic trend.

2.4.3 Previous Studies of the LOP in the U.S./Canadian Agricultural Trade

2.4.3.1 Various Analyses

Richardson (1978) studied a disaggregated commodity arbitrage between the United States and Canada using regression analysis. His main findings included: first, commodity arbitrage takes place, but not significantly for every commodity group; second, commodity arbitrage is never perfect; third, when commodity arbitrage is detected, Canadian prices invariably respond as much or more to the exchange rate as they do to U.S. prices. Richardson's database consists of monthly observations on Canadian price indexes at the 4 and 7-digit level of Standard Industrial Classifications, and "roughly comparable U.S. price indexes," over the period 1965 through 1974. Prices are denominated in terms of Canadian and U.S. dollars. To avoid problems posed by autocorrelated residuals and lack of information on transaction costs, Richardson implements his tests using growth rates instead of levels. Thus, Richardson regressed the growth rate of the domestic price on the growth rates of the foreign price and the exchange rate. Among other conclusions, he found that "the hypothesis of perfect commodity arbitrage is rejected with 95 percent confidence for every commodity"(p.347).

Ardeni (1989) investigated the LOP in the long run for four countries: the United States, Canada, Australia and the United Kingdom. The study was conducted on a small number of commodities: wheat, wool, beef, sugar, tea, tin and zinc. He used quarterly data for export (import) prices adjusted for exchange rates for the time period of twenty years: 1965 to 1985. The testing results are quite unsupportive to the LOP. The U.S. wheat (export price) and Canadian wheat (export price) is one pair of goods among a total of three that show favorable evidence to the LOP. In general, however, the presumption that digression of the LOP from the long-run equilibrium condition is transitory cannot be sustained.

Engel and Rogers (1996) examined how much the distance between cities and the national border between the United States and Canada are related to the deviations from the LOP. They employed Consumer Price Index data disaggregated into 14 categories of goods for nine Canadian cities and fourteen cities in the U.S., covering the period from 1978 to 1994. The research results verified that both distance and the national border play significant roles in explaining price variation of similar goods among different locations. However, the price differential is much lower for two cities in the same country than for two equidistant cities located in different counties. Nominal price stickiness, integration of labor markets and trade barriers are possible explanations for this price variability.

Carlson *et al.* (1999) compared pesticide prices between the U.S. and Canada and investigated the reasons for price variations. They chose the prairie provinces of Canada and North Dakota and Minnesota in the U.S. as the study areas because of their similarities in climates, technology and general concerns among farmers for pesticide prices. The study focused on the following crops: spring wheat, barley, canola and potatoes. The restriction in the movement of pesticides across nation borders is one of the basic reasons for price differential of similar pesticides between the U.S. and Canada. In addition, demand, production costs, market size, market segmentation, patent status, and availability of substitutes comprise of other factors influencing the pricing decisions of pesticide manufacturers.

2.4.3.2 Analyses by Carter and Co-authors

Carter and Hamilton (1989) contributed to the LOP literature by testing the LOP from the perspective of tradable inputs in commodity production. They studied the validity of the LOP for wheat inputs tradable between Canada and the United States. The analysis was conducted with the background that Canadian and the U.S. farmers use similar wheat inputs of which trade between the two countries is relatively free of barriers. The statistical test results denied the LOP as applied to wheat inputs, however, the authors argued that one cannot conclude there is no relationship between the U.S. wheat input prices and Canadian wheat input prices. The price differential is possibly due to government regulation, varying levels of product differentiation, and the lack of competitive forces.

The later paper by Carter, Gray and Furtan (1990) is what this study is based on. Carter *et al.* estimated exchange rate effects on inputs and outputs in Canadian agriculture, particularly when both inputs and outputs are tradable. The empirical results showed that "exchange rate pass-through on the major variable inputs used in Canadian agriculture is significant" (p.742), although a difference occurs in the rate of pass-through. Exchange rate movements play a role in price fluctuations of both inputs and outputs in Canadian agriculture. However, it only explains a small part of the changes in the relative Canadian/U.S. prices. Specifically, Carter *et al* concluded that their estimation showed strong support for a contemporaneous exchange rate pass-through on wheat, canola, and petroleum, a one-quarter lagged pass-through on feeder steers, fat steers, and pesticides, and a two-quarter lagged pass-through on fertilizer and no pass-through on farm machinery. Their results are discussed in greater detail in Chapter 3.

Chapter III – An Empirical Analysis of the LOP for U.S. and Canadian Agricultural Output and Input Prices

3.1 The Dynamic Econometric Model to Test the LOP Hypothesis

In this chapter, a dynamic econometric model is built upon Carter *et al*'s paper to test the LOP hypothesis and estimate exchange rate pass-through on agricultural output and input prices. First, Carter *et al*'s original estimation over their sample period starting from the first quarter of 1975 to the second quarter of 1988 is replicated using similar data sources. Then, Carter *et al*'s analysis is extended in the following three ways: 1) The sample period is extended by eleven years until the fourth quarter of 1999; 2) besides the original two quarter lags in the Carter *et al*'s models, alternative lag lengths are incorporated, with separate regressions run with zero lags, one lag, four lags and eight lags; and 3) an additional price series (corn) is added to the estimation. The primary purpose of the models is to test if Carter *et al*'s results are robust over the extended time period. By utilizing various lengths of exchange rate lags within this framework, the hypothesis of the LOP validity as a short-run, intermediate-run, or medium-run relationship is analyzed. The regression results and criteria are compared and measured, and optimal lag length is chosen to determine the most appropriate model specification for evaluating exchange rate change effects on agricultural prices. Finally, the stationarity properties of the individual series and linear combination of prices expressed in a common currency are examined to determine whether the Carter *et al* model specification excluded information for levels of the data, and whether the LOP holds in a cointegrating equilibrium relationship.

The LOP predicts that Canadian prices should equal the U.S. prices converted to Canadian dollars, plus any transfer costs (tariffs and transportation). This relationship can be written as

$$P_t^c = P_t^u * E + \Phi, \tag{3.1}$$

where P_t^c and P_t^u are the commodity prices of Canada and the U.S. at time period *t*, respectively; E is the exchange rate as the units of Canadian dollar per U.S. dollar; and Φ is (for a good imported by Canada) the anticipated transfer cost in moving the commodity from the U.S. market to Canadian market. Equation (3.1) is the LOP in its strict form.

In attempting to estimate this equation, a few data and statistical issues are encountered. The first consideration is that independent information about transfer costs is difficult to obtain. Some authors in the literature also maintain that the LOP is a long-run equilibrium concept and does not depend on the actual transfer of goods. For example, Ardeni (1989) assumed that transfer cost is constant or proportional to commodity prices over the sample period and removed this variable from the equation. Thus, the transportation cost is often ignored in the LOP analysis. In this study, the transportation costs could be represented in the intercept term.

Secondly, estimating an equation of the above form could lead to spurious regression problems, since regressions of price levels necessitate that the price series be stationary. The most common approach is to take first differences of all nonstationary variables before specifying the model. Davidson and Mackinnon (1993) showed some of the consequences of spurious regressions in econometrics induced by the time-series properties of the variables analyzed. They argued that many variables are nonstationary in their levels and appear to be near-random walks. Nonstationarity would make classical asymptotic theory inapplicable and the usual estimation procedures would be invalidated. Thus, the phenomenon of spurious regression appears to be one compelling reason for taking first differences of nonstationary variables to induce stationarity in estimating regressions. Because time-series data may trend over time, i.e. a stochastic trend, a spurious regression might exist in the presence of nonstationary variables.

Thirdly, the LOP relationship is multiplicative in levels, but linear in log-levels. Thus, testing in a linear regression should be conducted with logged (natural logs) data. This has an additional advantage that taking the natural logarithm of variables in models to be estimated could induce stationarity for one type of nonstationary time series. Even for first-differenced level series, the sequence might exhibit an explosive portion, where fluctuations are more violent for a particular segment of the sequence than for others. Then a constant variance dose not exist throughout the differenced series. By taking the natural logarithm of each observation, so differences are percent changes, this transformation will reduce the swings of the levels which constitute the variance nonstationarity and induce variance stationarity in the series. This usually yields a series which approximates well one having constant variance.

Finally, utilizing the data in differences and percentage changes reduces the potential for another problem associated with using time-series data, i.e. serial correlation. The phenomenon of serial correlation, in which successive residuals appear to be correlated with each other, is very often encountered in models estimated with time-series data. The serial correlation violates the standard assumption of regression theory that disturbances are not correlated, causing ordinary least squares estimates (OLS) to be inefficient and makes inference based on them invalid, even when there are no lagged dependent variables. When there are lagged dependent variables, serial correlation causes OLS to be biased and inconsistent.

Therefore, rates of change in logged price levels are used in estimation rather than absolute price levels as in equation (3.1). Taking logs and first differencing equation (3.1) yields the equation:

$$Log(P_t^c / P_{t-1}^c) = Log(P_t^u / P_{t-1}^u) + Log(E_t / E_{t-1}) \tag{3.2}$$

For estimation the equation is reformulated as:

$$Log(P_t^c / P_t^u) - Log(P_{t-1}^c / P_{t-1}^u) = C + \beta_0 * Log(E_t / E_{t-1}) + \varepsilon_t \tag{3.3}$$

where

P_t^c = the Canadian dollar price of the commodity at time period t

P_t^u = the U.S. dollar price of the commodity at time period t

P_{t-1}^c = the Canadian dollar price of the commodity at time period (t-1)

P_{t-1}^u = the U.S. dollar price of the commodity at time period (t-1)

C = the intercept term

β_0 = the contemporaneous coefficient of exchange rate pass-through

E_t = the exchange rate of \$CN/\$US at time period t

E_{t-1} = the exchange rate of \$CN/\$US at time period (t-1)

ε_t = the residual term

Adherence to the LOP implies that parameter β_0 is not significantly different from one and the mean of ε_t is zero, then there is a complete contemporaneous exchange rate pass-through on commodity prices. If β_0 is less than one, then there must be sticky prices for exchange rate movements, the contemporaneous exchange rate pass-through is incomplete and the LOP does not hold up instantaneously. But some lag time might be expected before prices completely reflect changes in exchange rates. Even in the hypothetical world of perfect market clearing an adjustment period may be necessary. Therefore, it is reasoned that such an equation as (3.3) may contain a built-in bias against the LOP, since no lag structure is present, only the immediate price reaction to a change in the exchange rate is measured.

If prices do not show immediate and full adjustment to exchange rate changes, the question of how long they would remain sluggish is important to investigate. Because the LOP may be valid in a short, intermediate, medium or long run, the rate at which the exchange rate movements are completely transmitted through to commodity prices should be examined. Therefore, a system of lags on the independent variable exchange rates is instituted in the regression analysis. The more general models with different lengths of lagged exchange rates to capture the lagged effects of exchange rates on prices take the form:

$$Log(P^{c}_{t-i} / P^{u}_{t-i}) - Log(P^{c}_{t-i-1} / P^{u}_{t-i-1}) = C + \sum_{i=0}^{n} \beta_{i} * Log(E_{t-i} / E_{t-i-1}) + \varepsilon_t \qquad (3.4)$$

where *n* gives the numbers of lagged terms in models.

3.2 Data Description and Analysis

In this study, the LOP is tested on five farm outputs, namely: wheat, soybeans, corn, feeder steers, and slaughter steers.[1] These commodities are important to Canadian and U.S. agriculture in terms of their contribution to income, employment and foreign exchange earnings. Three of the outputs (soybeans, corn, and feeder steers) also are inputs to production of slaughter steers. In addition, the LOP is tested for four non-farm produced inputs: fertilizer, pesticides, petroleum, and farm machinery. Together, these farm outputs and non-farm produced inputs comprise a large percentage of the total value of farm output and costs involved in agricultural production besides labor, management,

[1] Carter *et al* used the term “fat steers” in their analysis, which is “slaughter steers” in our study.

and land. The sample covers the period from the first quarter of 1975 to the fourth quarter of 1999. The data used in the analysis are quarterly, some of which are converted from monthly data sources. The initial exchange rate data is a monthly nominal exchange rate as compiled by the Economic Research Service (hereafter ERS), U.S. Department of Agriculture (USDA). Details for all the price data used in the analysis are provided in Appendix tables A and B.

The decision to perform the investigation based on narrowly-defined homogenous output and input commodities is motivated by the fact that the arbitrage mechanism is believed to be applicable to closely substitutable goods. Accordingly, the commodity data employed in the present analysis include quarterly average prices for specific qualities of grains, oilseeds and livestock at a specific location in each country. The series closely match the series used in the earlier analysis by Carter *et al*.[2]

The U.S. wheat price data are monthly average of No.1, hard red winter, ordinary protein wheat at Kansas City and the Canadian prices are No.1, Canadian western red spring wheat, 13.5% in-store at St. Lawrence. Both are quoted in $US/metric ton and compiled by ERS, USDA in the publication *Wheat Situation and Outlook Yearbook*. For the analysis, the published Canadian prices in U.S. dollars are re-converted to $CN/metric ton by the nominal exchange rate of $CN/$US. The U.S. soybean and corn price series used are average monthly cash prices of No.1 yellow soybeans and No.2 yellow corn at Chicago, quoted in $US/bushel. They are also obtained from ERS, USDA. The Canadian counterparts are producer prices at Ontario, Canada, quoted in $CN/tonne and provided by Statistics Canada. The U.S. soybean and corn data are transformed to tons to utilize common units in the estimation procedure. The factor used for conversion is 1 tonne = 1 metric ton = 36.7437 bushels of soybeans, and 39.3679 bushels of corn.

The U.S. feeder steer price data used are medium No.1 feeder steers weighed 750 – 800 pounds at Oklahoma City, quoted in $US/100lbs. The Canadian counterparts are quarterly average prices at Calgary (1975-93) and Saskatchewan (1994-99), weighed 800 – 900 pounds and quoted in $CN/100lbs. The U.S. slaughter steer prices are choice

[2] Carter *et al* were not able to provide their original data (personal correspondence). We followed their approach by using similar farm output price series, and available price indices for non-farm produced inputs fertilizer, pesticides, petroleum, and farm machinery.

steers weighed 1,100 – 1,300 pounds at Texas, quoted in $US/100lbs. The Canadian slaughter steer price data are average prices quoted in $CN/100lbs at Winnipeg (1975-93) and Manitoba (1994-99), weighed 1,000lbs and over. The U.S. livestock price data are obtained from ERS, USDA. The corresponding Canadian data are partly derived from Statistics Canada and partly provided by Agriculture and Agri-Food Canada.

As to the input price data, the quarterly relative prices of fertilizer, pesticides, petroleum and farm machinery are all price indexes based on the four-quarter average for 1986 = 100. Each of these input price series are derived from "Prices Paid Indexes" in various issues of *Agricultural Prices* published by National Agricultural Statistics Service (NASS), USDA. The Canadian counterparts are obtained from Statistics Canada's quarterly publication *Farm Input Price Indexes*.

Time plots of the exchange rate and the output and input price series appear in figure 3-1 through 3-10, so a visual picture of the prices movements in the U.S. and Canada since 1975 can be gained. Both the Canadian and U.S. output prices are expressed in the Canadian dollars ($CN), so the LOP implies close movement of their levels. For the non-farm produced input series, the U.S. indices are multiplied by the exchange rate, and then re-scaled to the average for 1986 = 100 again. Thus, for non-farm produced inputs, the index values are identical in 1986. The LOP can not be evaluated in absolute terms for the levels of these non-farm produced input prices, but the LOP implies these series move closely together over time.

As shown in figure 3-1, there are two periods of the exchange rate $CN/$US depreciation during 1975 – 1986 and 1991 – 1999. The nominal depreciation since 1991 slowed during 1994 through 1997. In figures 3-2 through 3-7, although a gap could be observed in some periods, the wheat, soybean, corn, feeder steer, slaughter steer, and fertilizer prices in Canada and the U.S. generally move closely together and the LOP seems to hold for those commodities. The time plots for pesticide and petroleum prices of both countries seem to move apart for some time, but tend to move back together. They do not present an apparent relationship of persistent close movements between the two countries, so the LOP seems to hold somewhat less for these two inputs. Farm machinery prices present a long time departure from each other throughout the whole sample period and do not tend to move together, thus the prices appear to show a deviation from the LOP. If Canadian and the U.S. input prices fail to equilibrate according to the LOP, the country which experiences an increase in relative costs will be placed at a competitive disadvantage. The empirical evidence in the following sections will show statistically the relationships between prices in Canada and the U.S.

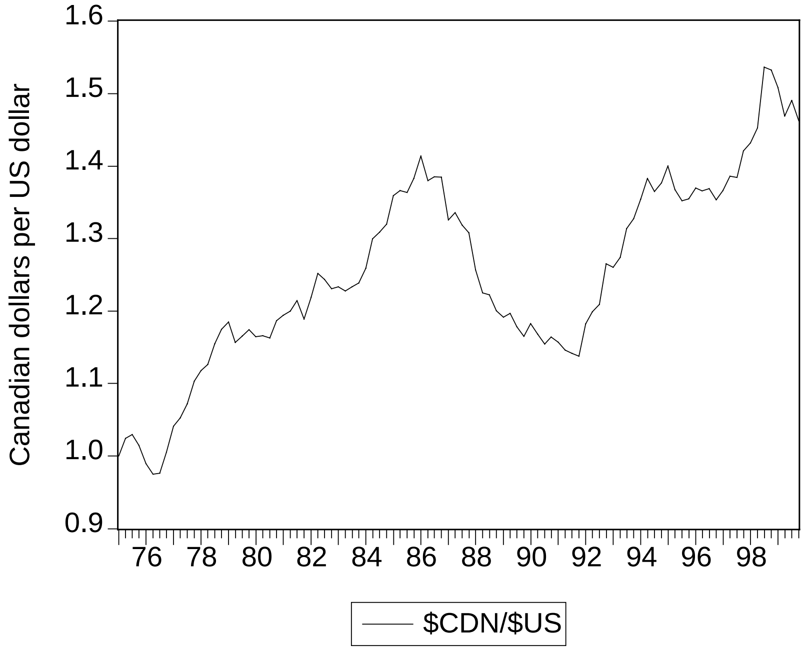

Figure 3-1. The nominal exchange rate between Canada and the U.S.

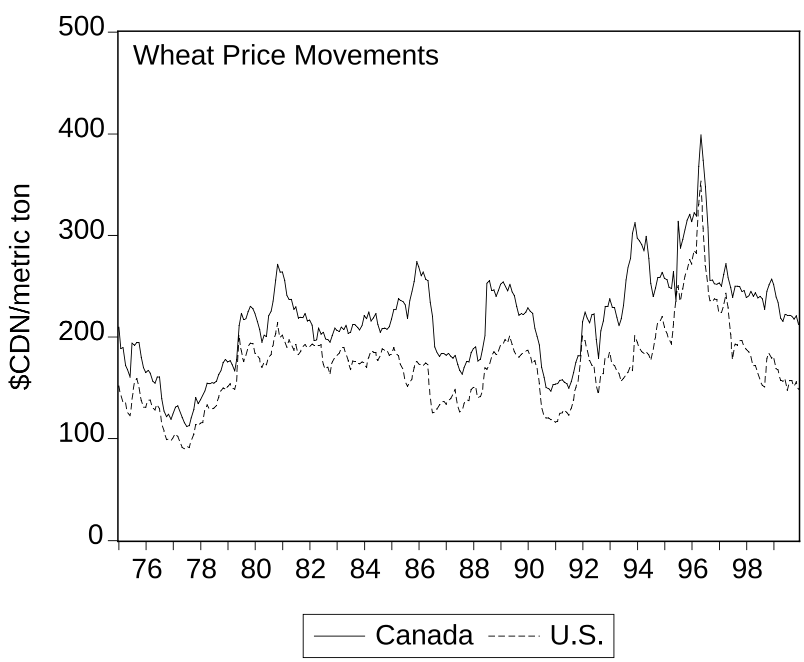

Figure 3-2. Prices of Canadian and U.S. wheat in Canadian dollars.

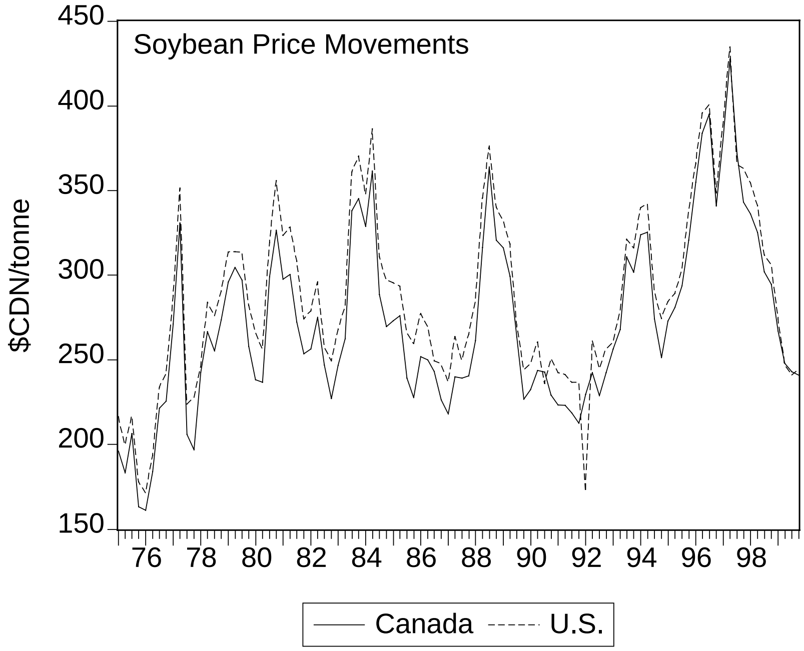

Figure 3-3. Prices of Canadian and U.S. soybeans in Canadian dollars.

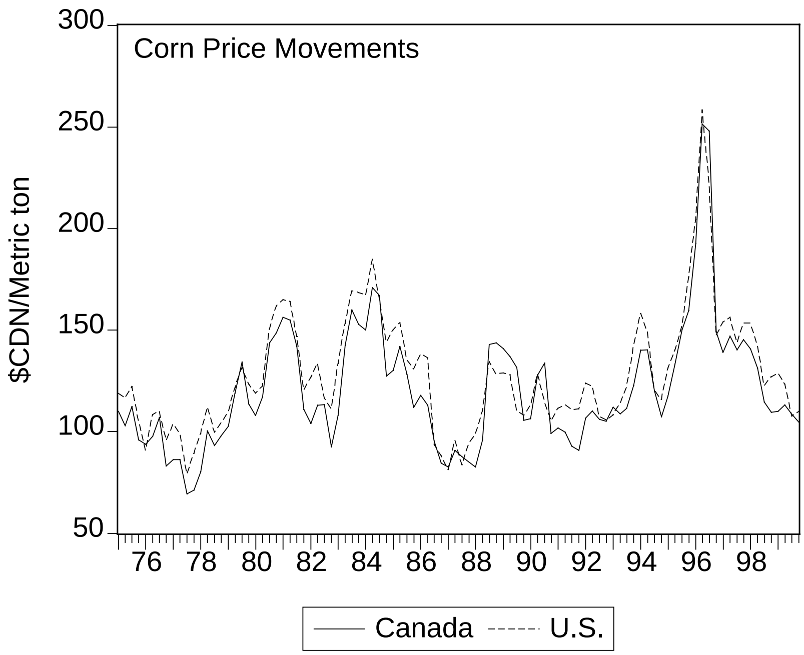

Figure 3-4. Prices of Canadian and U.S. corn in Canadian dollars.

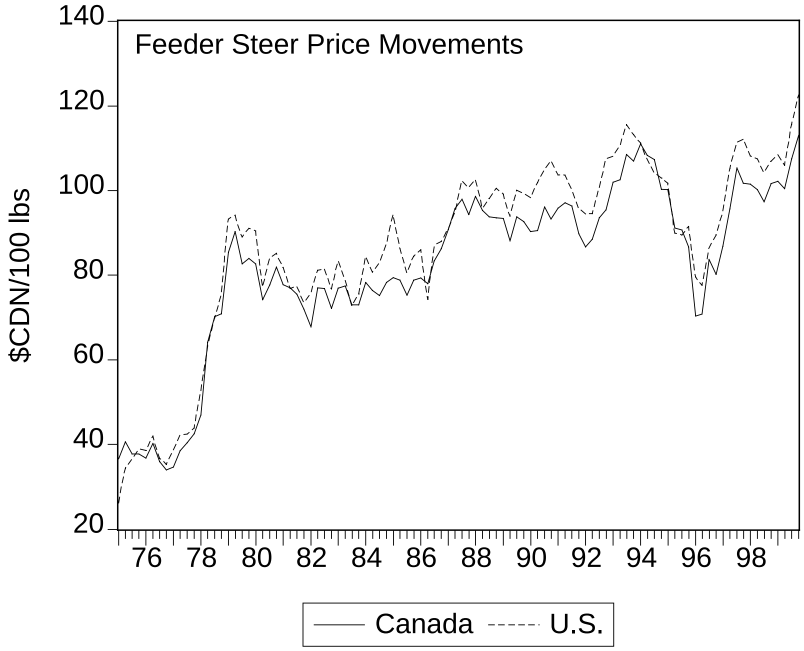

Figure 3-5. Prices of Canadian and U.S. feeder steers in Canadian dollars.

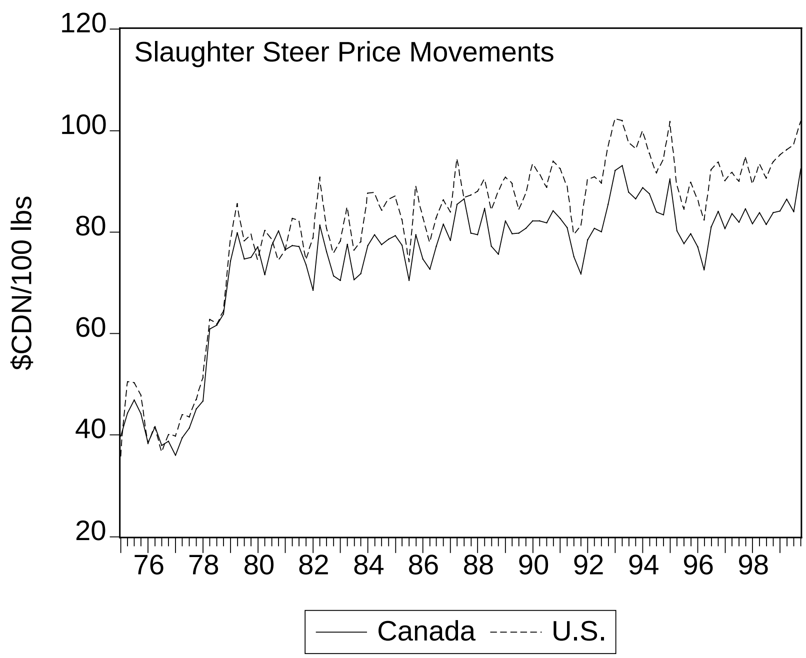

Figure 3-6. Prices of Canadian and U.S. slaughter steers in Canadian dollars.

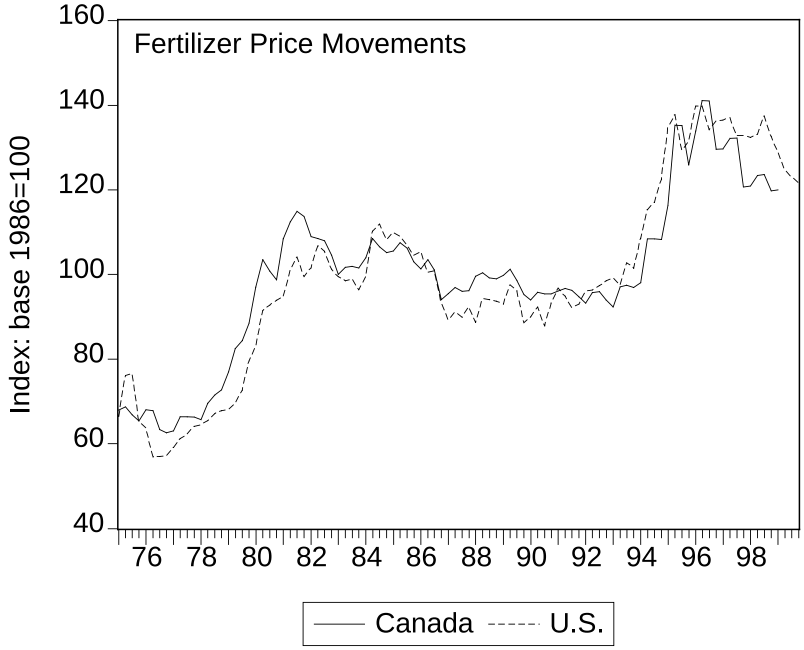

Figure 3-7. Prices of Canadian and U.S. fertilizer in Canadian dollars.

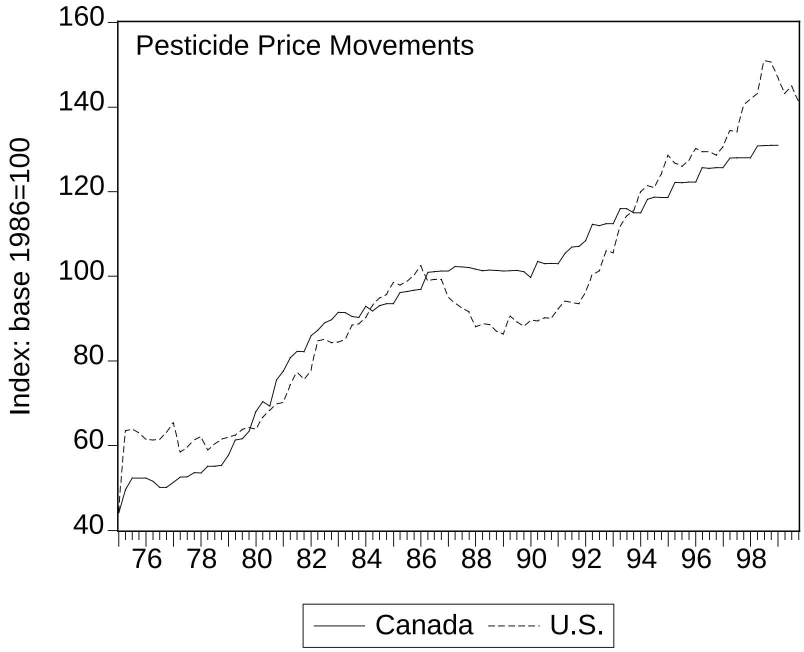

Figure 3-8. Prices of Canadian and U.S. pesticides in Canadian dollars.

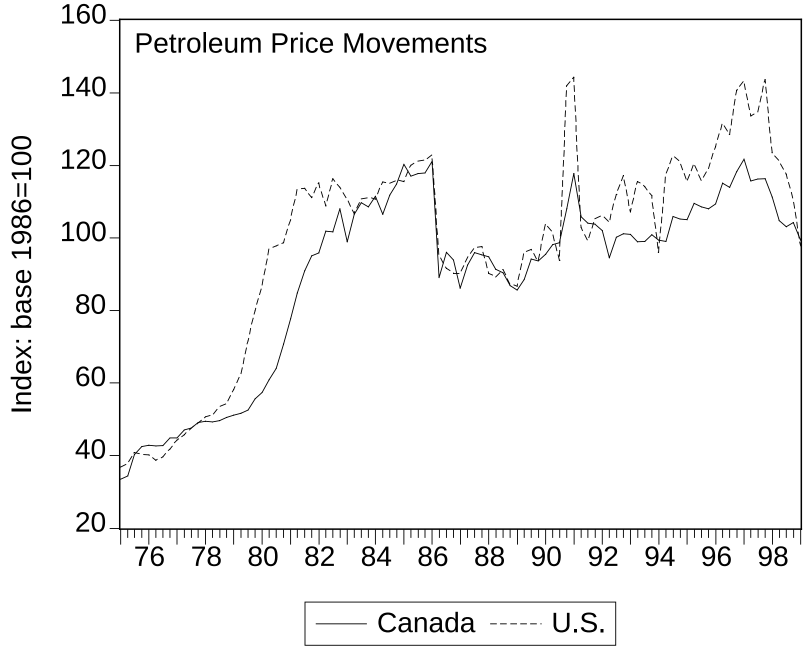

Figure 3-9. Prices of Canadian and U.S. petroleum in Canadian dollars.

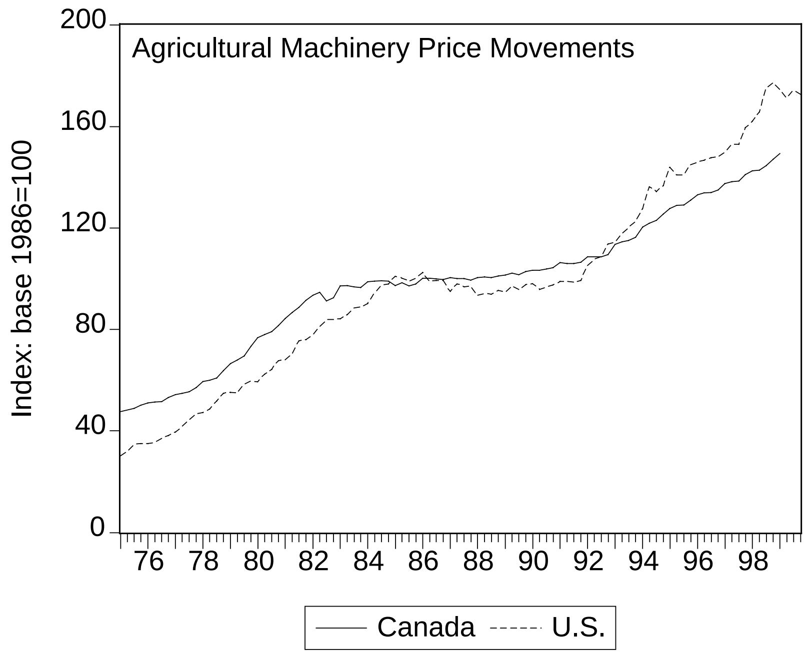

Figure 3-10. Prices of Canadian and U.S. farm machinery in Canadian dollars.

3.3 Empirical Results of Carter *et al* over the Sample Period 1975-1988

Carter *et al*'s model specification includes two lagged quarters. They used OLS to estimate equation (3.4) for four farm outputs (wheat, canola/soybeans,[3] feeder steers, and fat steers), and four non-farm produced inputs (fertilizer, pesticides, petroleum, and farm machinery) in Canadian and U.S. agriculture.

Carter *et al's* original regression results are summarized in table 3-1. The parameter estimates $\hat{\beta}_0$, $\hat{\beta}_1$, and $\hat{\beta}_2$, student *t*-tests, and the sums of estimated parameters ($\hat{\beta}_0+\hat{\beta}_1$) and ($\hat{\beta}_0+\hat{\beta}_1+\hat{\beta}_2$) are reported along with R^2 for the regressions. The point-estimate values of contemporaneous pass-through $\hat{\beta}_0$ are different across commodities, among which only the $\hat{\beta}_0$'s of wheat, canola, and petroleum are significantly different from zero, rejecting the null hypothesis of no contemporaneous exchange rate pass-through. Thus, wheat, canola, and petroleum prices show statistically significant pass-through immediately. None of the $\hat{\beta}_1$'s are statistically different from zero individually, although the point estimates of pass-through increase for all commodities except petroleum with a one-quarter lag. For fertilizer and pesticides, the *t*-statistics 1.85 and 2.57 for testing $\hat{\beta}_2 = 0$ reject zero pass-through in the second lagged period, hence, it appears to take three to six months to get significant exchange rate pass-through for fertilizer and pesticide prices. The LOP appears valid based on point estimates for pesticide prices after two quarters, since pesticides get complete pass-through (i.e. the point estimate of the sum of the coefficients $\hat{\beta}_i$ (i = 0, 1, 2)) 1.01. But the LOP is not clear for fertilizer even after two quarters, since the sum of coefficients is only 0.46, the lowest value except for farm machinery. The general implication from the regressions supports a contemporaneous LOP for canola and petroleum, one-lagged LOP for wheat, and two-lagged LOP for feeder steers, fat steers, and pesticides. There is

[3] Carter *et al* used Canadian canola prices and U.S. soybean prices, respectively, in the equation for estimating the exchange rate effects on oilseeds.

Table 3-1. Carter *et al*'s Original Regression Results

Commodity	β_0	β_1	β_2	$\beta_0+\beta_1$	$\beta_0+\beta_1+\beta_2$		R^2
	t-Stat for H_0: $\beta_0=0$	*t*-Stat for H_0: $\beta_1=0$	*t*-Stat for H_0: $\beta_2=0$		*t*-Stat for H_0: $\sum\beta=1$ (Law of One Price)	*t*-Stat for H_0: $\sum\beta=0$ (Zero Pass-through)	
Wheat	.64	.39	.09	1.03	1.12		.14
	(2.03)**	(1.21)	(.27)		(.27)	(2.40)**	
Canola/Soya	.93	.65	-.15	1.58	1.43		.12
	(1.82)*	(1.25)	(.27)		(.56)	(1.89)*	
Feeder Steers	.14	.46	.63	.6	1.23		.06
	(.27)	(.88)	(1.12)		(.31)	(1.60)	
Fat Steers	.60	.14	.19	.74	.93		.05
	(1.32)	(.32)	(.42)		(.08)	(1.41)	
Fertilizer	-.41	.35	.52	-.06	.46		.13
	(1.56)	(1.32)	(1.85)*		(1.38)	(1.19)	
Pesticides	.13	.31	.57	.44	1.01		.20
	(.65)	(1.51)	(2.57)**		(.04)	(3.36)**	
Petroleum	1.27	-.33	-.21	.94	.73		.15
	(2.91)*	(.74)	(.46)		(.42)	(1.11)	
Machinery	.19	.09	-.17	.28	.11		.06
	(1.23)	(.61)	(1.05)		(3.9)**	(.48)	

Notes:

1. Calculated *t*-statistics are shown in brackets. Critical *t*-values for two-tailed *t*-test are 1.65 (90 percent confidence) and 1.96 (95 percent confidence).
2. A single star (*) denotes statistically different from zero at the .10 significance level.
3. A double star (**) denotes statistically different from zero at the .05 significance level.

Source: Carter, C. A., R. S. Gray, and W. H. Furtan, "Exchange Rate Effects on Inputs and Outputs in Canadian Agriculture," *American Journal of Agricultural Economics*, 72 (1990): p.742.

essentially no pass-through for farm machinery.[4] Student *t* values for the hypotheses of $\sum \beta = 1$ and $\sum \beta = 0$ are reported, which are tests of a complete pass-through and no pass-through, respectively, over six months. The *t*-statistic rejects zero pass-through for wheat, canola, and pesticides. For feeder steers, fat steers, and fertilizer, although the pass-through increases over time, the statistic evidence is not strong enough to reject either of the null hypotheses. For farm machinery, the *t*-statistic 3.9 strongly rejects the null hypothesis of the law of one price.

3.4 Extension of Carter *et al*'s Analysis

Our analysis extends Carter *et al*'s assessment, using similar data. Alternative lengths for the lag on the explanatory variable are empirically tested by ordinary least squares. Examining the LOP as a short-run relationship is assumed to be conducted in the model lagged two quarters (n = 2 in equation 3.4). An intermediate-run model is assumed to incorporate four-quarter lags (n = 4) and the medium-run model for testing the LOP adopts eight quarters as lags (n = 8). Tables from 3-2 to 3-4 report regression estimates with different lag length for the five outputs and four inputs over our full sample period 1975-1999. Tests of the LOP and zero pass-through are shown for the sum of coefficients in the models in table 3-5 and 3-6, and table 3-7 shows the sum of the point estimates for each model, for estimation both over the full sample and Carter *et al*'s original sample period.

First, to see if Carter *et al*'s results are robust over the longer sample period, we replicate Carter *et al*'s estimation using our data sources in the same framework but extending the sample until the fourth quarter of 1999. Given the two lagged variables, Carter *et al*'s data yield fifty-two observations. Added eleven more years, our data give rise to ninety-eight observations.

As shown in table 3-2, the values of the parameter estimates in our short-run model support a contemporaneous pass-through for wheat and soybeans: for these commodities the coefficient point estimates suggest a more than proportionate change in

[4] Carter *et al* gave a somewhat different conclusion in their paper: "the data strongly support a contemporaneous pass-through for wheat, canola, and petroleum, a one-quarter lagged pass-through for feeder steers, fat steers, and pesticides, and a two-quarter lagged pass-through for fertilizer and no pass-through for farm machinery" (Carter, Gray and Furtan 1990, p.741).

Table 3-2. Regression Results of Model Lagged Two Quarters over the Full Sample 1975-99

Commodity	Parameter Estimates				R^2	DW	Akaike info Criterion	Schwarz Criterion
	C	β_0	β_1	β_2				
Wheat	-.001 (-.22)	1.74 (5.17)**	-.002 (-.01)	-.07 (-.19)	.23	2.11	-2.83	-2.73
Soybeans	.001 (.16)	1.19 (3.14)**	-.32 (-.82)	-.05 (-.13)	.10	3.03	-2.60	-2.49
Corn	.0002 (.03)	.45 (.95)	.48 (.99)	.07 (.15)	.03	2.34	-2.15	-2.04
Feeder Steers	-.002 (-.45)	.39 (1.65)*	.55 (2.24)**	.21 (.86)	.11	2.60	-3.54	-3.43
Slaughter Steers	.0004 (.09)	.40 (1.63)	.52 (2.05)**	-.14 (-.56)	.08	2.58	-3.37	-3.37
Fertilizer	.002 (.45)	-.37 (-1.64)	.37 (1.62)	.61 (2.72)**	.13	2.23	-3.70	-3.59
Pesticides	.002 (.68)	.04 (.22)	.33 (1.94)*	.31 (1.88)*	.10	2.18	-4.34	-4.23
Petroleum	.0002 (.02)	.32 (.75)	.41 (.93)	.25 (.58)	.03	2.40	-2.41	-2.30
Machinery	-.002 (-1.003)	.09 (.74)	.23 (1.81)*	-.08 (-.64)	.05	2.17	-4.89	-4.78

Notes:

1.Calculated *t*-statistics are shown in brackets. Critical *t*-values for two-tailed *t*-test are 1.65 (90 percent confidence) and 1.96 (95 percent confidence).

2. A single star (*) denotes statistically different from zero at the .10 significance level.

3.A double star (**) denotes statistically different from zero at .05 significance level.

prices in Canada versus the U.S. There is a one-lagged pass-through for corn, feeder steers, and slaughter steers, and two-lagged pass-through for petroleum and to a less extent fertilizer and pesticides based on the coefficient estimates. There is essentially no pass-through for farm machinery. Contemporaneous coefficients are estimated to be significantly different from zero in the wheat, soybean, and feeder steer equations, while one-quarter lagged coefficients are significant in the feeder steer, slaughter steer, pesticide, and farm machinery equations, and two-quarter lags in the fertilizer and pesticide equations. Comparing Carter *et al*'s original findings in table 3-1 with ours, similar contemporaneous results are obtained for canola/soybeans, and for the pattern of coefficients for three non-farm produced inputs (fertilizer, pesticides, and farm machinery), although pesticide prices get less pass-through (0.68) over six months with our data and full sample than in Carter *et al* (1.01). Prices of wheat, feeder steers, and slaughter steers over our full sample present more response to exchange rate changes contemporaneously or with a one-quarter lag than shown in Carter *et al*.

Adding two more lags to the short-run model, we obtain the intermediate-run model, where adjustments are measured over a full year. The regression results of this four-quarter lag model are reported in tables 3-3. As shown, the values of contemporaneous pass-through $\hat{\beta}_0$ again support a statistically significant within-quarter pass-through for wheat and soybeans. The estimates of lagged terms $\hat{\beta}_i$ (i = 1, 2, 3, 4) show that one-lagged pass-through is significant for feeder steers, slaughter steers, fertilizer, and pesticides. Two-lagged pass-through for fertilizer and pesticides is also statistically different from zero. The pass-through in the third and fourth lags are all insignificant since their t-statistics are lower than the critical t-values in each case. In all, compared with the short-run model, we obtain similar results from the intermediate-run model regressions, i.e. a contemporaneous pass-through for wheat and soybeans; one-lagged pass-through for corn and livestock; two-lagged pass-through for fertilizer, pesticides, and petroleum; and essentially no pass-through for farm machinery.

Turning to the medium-run model with eight lag terms, as reported in table 3-4, the parameter estimates support a contemporaneous LOP for wheat, soybeans, and corn. Livestock prices get complete pass-through after three months. The pass-through for

Table 3-3. Regression Results of Model Lagged Four Quarters over the Full Sample 1975-99

Commodity	Parameter Estimates						R^2	DW	Akaike info Criterion	Schwarz Criterion
	C	β_0	β_1	β_2	β_3	β_4				
Wheat	-.001 (-.08)	1.82 (4.95)**	-.04 (-.12)	-.01 (-.02)	-.31 (-.81)	.05 (.15)	.23	2.11	-2.78	-2.62
Soybeans	.0003 (.05)	1.31 (3.18)**	-.45 (-1.09)	.04 (.11)	-.38 (-.90)	.47 (1.14)	.11	3.04	-2.56	-2.40
Corn	-.001 (-.16)	.74 (1.45)	.41 (.80)	.18 (.37)	-.63 (-1.20)	.42 (.82)	.05	2.23	-2.13	-1.97
Feeder Steers	-.0005 (-.11)	.27 (1.06)	.58 (2.29)**	.24 (.99)	.14 (.53)	-.16 (-.62)	.12	2.68	-3.53	-3.37
Slaughter Steers	-.002 (-.33)	.39 (1.49)	.52 (1.98)**	-.19 (-.75)	.22 (.81)	.16 (.60)	.11	2.60	-3.47	-3.30
Fertilizer	.001 (.19)	-.24 (-1.01)	.46 (1.91)*	.55 (2.45)**	-.07 (-.29)	-.21 (-.83)	.13	2.32	-3.74	-3.58
Pesticides	.003 (.85)	.05 (.26)	.40 (2.16)**	.33 (1.95)*	-.07 (-.34)	-.19 (-1.03)	.11	2.18	-4.29	-4.13
Petroleum	.0002 (.02)	.35 (.72)	.49 (1.01)	.22 (.49)	-.01 (-.02)	-.22 (-.45)	.03	2.39	-2.35	-2.19
Machinery	-.003 (1.18)	.09 (.65)	.17 (1.23)	-.09 (-.71)	.03 (.21)	.17 (1.16)	.07	2.22	-4.84	-4.68

Notes:

1. Calculated *t*-statistics are shown in brackets. Critical *t*-values for two-tailed *t*-test are 1.65 (90 percent confidence) and 1.96 (95 percent confidence).
2. A single star (*) denotes statistically different from zero at the .10 significance level.
3. A double star (**) denotes statistically different from zero at .05 significance level.

Table 3-4. Regression Results of Model Lagged Eight Quarters over the Full Sample 1975-99

Commodity	Parameter Estimates										R^2	DW	Akaike info Criterion	Schwarz Criterion
	C	β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8				
Wheat	.0001 (.01)	1.89 (4.65)**	-.12 (-.31)	.06 (.15)	-.61 (-1.32)	.22 (.49)	.01 (.03)	.64 (1.45)	-.47 (-1.07)	-.15 (-.37)	.25	2.10	-2.68	-2.41
Soybeans	.0004 (.05)	1.33 (2.89)**	-.50 (-1.11)	-.0001 (-.0003)	-.41 (-.80)	.62 (1.22)	.04 (.08)	-.10 (-.20)	-.33 (-.67)	.37 (.79)	.12	3.03	-2.44	-2.17
Corn	.001 (.10)	.97 (1.77)*	.32 (.60)	.22 (.41)	-1.01 (-1.63)	.32 (.54)	-.32 (-.54)	.57 (.95)	.32 (.54)	-.09 (-.15)	.08	2.24	-2.08	-1.81
Feeder steers	-.001 (-.15)	.33 (1.20)	.70 (2.60)**	.22 (.82)	.06 (.20)	-.25 (-.83)	.30 (1.04)	.18 (.60)	-.23 (-.77)	-.20 (-.72)	.18	2.74	-3.48	-3.20
Slaughter steers	-.001 (-.11)	.53 (1.84)*	.59 (2.09)**	-.14 (-.49)	.12 (.36)	.10 (.32)	-.18 (-.59)	-.01 (-.03)	-.04 (-.13)	.10 (.32)	.14	2.66	-3.38	-3.10
Fertilizer	-.001 (-.32)	-.20 (-.88)	.60 (2.64)**	.39 (1.71)*	-.31 (-1.16)	-.35 (-1.35)	.64 (2.55)**	.50 (2.13)**	-.35 (-1.47)	-.06 (-.26)	.32	2.50	-3.95	-3.67
Pesticides	.002 (.73)	.06 (.29)	.40 (1.97)**	.24 (1.21)	-.08 (-.37)	-.24 (-1.04)	.12 (.53)	-.03 (-.12)	.07 (.35)	.16 (.80)	.11	2.02	-4.18	-3.90
Petroleum	.0003 (.04)	.27 (.51)	.77 (1.45)	-.08 (-.16)	.30 (.49)	-.45 (-.75)	.77 (1.34)	-.80 (-1.47)	-.24 (-.44)	.15 (.30)	.09	2.37	-2.28	-2.00
Machinery	-.003 (-1.10)	-.05 (-.34)	.11 (.75)	-.24 (-1.73)	.15 (.90)	.25 (1.56)	.32 (2.02)**	-.09 (-.58)	-.12 (-.82)	.04 (.30)	.15	2.19	-4.888	-4.61

Notes:

1. CS denotes Carter *et al*'s sample from 1975:1 to 1988:2; FS denotes full sample from 1975:1 to 1999:4.

2. Calculated *t*-statistics are shown in brackets. Critical *t*-values for two-tailed *t*-test are 1.96 (95 percent confidence) and 2.58 (99 percent confidence).

3. A single star (*) denotes H_0 is rejected at .10 significance level.

4. A double star (**) denotes H_0 is rejected at .05 significance level.

fertilizer is significant in the first, second, fifth, and sixth lags, although the LOP seems to hold for fertilizer after two quarters. For farm machinery, five-lagged pass-through is significant, implying that farm machinery prices need long adjustment time, but the LOP does not hold even after two years. The empirical results from this medium-run model again do not change much the basic results from the short-run model.

In addition to the above results, tests are reported in table 3-5 for the null hypothesis that the contemporaneous quarter plus all the lagged effects sum to one, which implies complete exchange rate pass-through and adherence to the LOP for separate models with only contemporaneous effects (zero lags), or short (1 or 2 lags), intermediate (4 lags) or medium (8 lags) period of time for price adjustment. The *p*-values of the *F* statistics for the hypothesis that $\sum \hat{\beta} = 1$ are reported, both for the full sample regressions (FS), and for similar models estimated over the original sample of Carter *et al* (CS).[5] Results for 2, 4, and 8 lags for the full sample are for those models reported in tables 3-2 – 3-4. The cumulative effect of the exchange rate on prices is significantly different from unity at the standard 10% and 5% levels of significance if the *p*-values are smaller than 0.10 and 0.05, respectively, implying the LOP hypothesis is rejected accordingly.

As shown in the table, the LOP is rejected most apparently for farm machinery among all the commodities, since the *p*-values are lower than 0.10 in nine out of ten different lag length/sample cases. In the basic two-quarter lagged model, i.e. the original Carter *et al*'s model specification, there is no rejections to the null hypothesis of the LOP except farm machinery either over the Carter *et al* sample 1975-1988 or the full sample 1975-1999. Regarding models with short lags (0 and 1 lag), more rejections appear especially for non-farm produced inputs fertilizer and pesticides, but also for livestock. Turning to models with longer lags (4 and 8 lags), there are few changes compared to the two-lag model. Except farm machinery, the LOP hypothesis is accepted in most of the cases over either sample with long lags. In terms of timing, the LOP is accepted more and more strongly with the increase of lag length from zero to eight across commodities.

[5] Since their precise data series were not available, our re-estimation of their equations will not yield identical results for their sample period.

Table 3-5. *P*-values of *F*-tests for the Law of One Price

Commodity	*P*-value of *F*-statistic for H_0: $\sum \beta = 1$ (Law of One Price)									
	0 Lags		1 Lag		2 Lags		4 Lags		8 Lags	
	CS	FS	CS	FS	CS	FS	CS	FS	CS	FS
Wheat	.71	.03**	.38	.09*	.27	.17	.55	.38	.17	.54
Soybeans	.43	.73	.79	.80	.68	.75	.89	.98	.91	.99
Corn	.33	.31	.85	.95	.73	.99	.41	.90	.35	.76
Feeder Steers	.05**	.03**	.35	.78	.61	.68	.65	.84	.44	.83
Slaughter Steers	.07*	.02**	.75	.78	.35	.54	.62	.82	.72	.90
Fertilizer	.000007**	.00**	.01**	.003**	.23	.25	.44	.17	.39	.74
Pesticides	.005**	.000006**	.28	.01**	.82	.17	.71	.08*	.82	.41
Petroleum	.99	.18	.88	.75	.57	.97	.43	.82	.06*	.75
Machinery	.00007**	.00**	.008**	.00002**	.01*	.00007**	.10*	.004**	.68	.01**

Notes:

1. CS denotes Carter *et al*'s sample from 1975:1 to 1988:2; FS denotes the full sample from 1975:1 to 1999:4.
2. A single star (*) denotes H_0 is rejected at .10 significance level.
3. A double star (**) denotes H_0 is rejected at .05 significance level.

The *p*-values of the *F* statistic for the test that the contemporaneous quarter plus all the lagged effects sum to zero are reported in table 3-6. Low *p*-value now indicates rejection of zero exchange rate pass-through, and overall *p*-values reported in table 3-6 are lower than in table 3-5. In the two-quarter lag model, zero pass-through is strongly rejected for wheat and pesticides over either sample. There are more rejections in the full sample period than in Carter *et al*'s (five versus three). Results with less lags are somewhat mixed: the number of rejections rises to six with only one lag but drops to just two with no lags for the full sample. Even with no lags, however, the *p*-values show rejections of zero pass-through in four cases for the Carter *et al* sample. With longer lags, i.e. 4 and 8 lags, the results are generally similar to the two-lag model. We find for wheat, soybeans, and pesticides, the null hypothesis of zero pass-through is rejected in most of cases across various lag lengths, but the evidence becomes weaker as lags are added. For most other commodities, the evidence for rejecting zero pass-through is less strong with short lags than with long lags.

Although some of the results in tables 3-5 and 3-6 are unfavorable to the LOP, a clearer picture is obtained by comparing these two tables. The *p*-values in table 3-5 generally are much higher than those in table 3-6. If we choose the significance level to be 0.20, the *p*-values in the two-lag model in table 3-5 are generally larger (except farm machinery) with only two rejections (0.17) of the LOP among sixteen cases over both samples. The computed average of *p*-values for testing the LOP across commodities excluding farm machinery over Carter *et al* sample is 0.53 and over the full sample 0.57. The *p*-values for zero pass-through are generally lower, even if they were not less than the 0.10 significance level. The computed average is 0.30 over the Carter *et al* sample and 0.14 over the full sample. Zero pass-through is rejected at the 0.20 significance level in each case (even farm machinery) over the full sample. Hence, the overall data provide evidence that tend to reject $\sum\beta = 0$ in favor of $\sum\beta = 1$, even though the evidence is not always statistically significant at usually reported levels. Agricultural machinery is a different story. The data strongly indicate that there is no adherence to the LOP in the short, intermediate, or medium run.

The LOP validity or invalidity can be further examined with the summed parameters. Table 3-7 summarizes the sum of the contemporaneous and lagged

Table 3-6. *P*-values of *F*-tests for Zero Exchange Rate Pass-through

Commodity	*P*-value of *F*-statistic for H_0: $\sum \beta = 0$ (Zero Pass-through)									
	0 Lags		1 Lag		2 Lags		4 Lags		8 Lags	
	CS	FS	CS	FS	CS	FS	CS	FS	CS	FS
Wheat	.004**	.000001**	.004**	.00009**	.007**	.001**	.05**	.01**	.03**	.06*
Soybeans	.004**	.003**	.002**	.06*	.04**	.14	.04**	.13	.20	.24
Corn	.50	.24	.14	.10*	.17	.15	.10*	.17	.15	.20
Feeder Steers	.71	.11	.29	.005**	.22	.001**	.34	.01**	.93	.000**
Slaughter Steers	.78	.19	.11	.004**	.50	.03**	.08*	.01**	.26	.05**
Fertilizer	.10*	.19	.78	.67	.24	.06*	.20	.18	.02**	.03**
Pesticides	.88	.93	.06*	.03**	.007**	.006**	.10*	.07*	.17	.05**
Petroleum	.02**	.29	.11	.12	.37	.12	.67	.26	.26	.45
Machinery	.62	.33	.32	.11	.67	.18	.39	.08*	.20	.14

Notes:

1. CS denotes Carter *et al*'s sample from 1975:1 to 1988:2; FS denotes the full sample from 1975:1 to 1999:4.
2. A single star (*) denotes H_0 is rejected at .10 significance level.
3. A double star (**) denotes H_0 is rejected at .05 significance level.

Table 3-7. Sum of Estimated Parameters

Commodity		0 Lags	1 Lag		2 Lags			4 Lags				8 Lags				
		β_0	β_0	$\sum_{i=0}^{1}\beta$	β_0	$\sum_{i=0}^{1}\beta$	$\sum_{i=0}^{2}\beta$	β_0	$\sum_{i=0}^{1}\beta$	$\sum_{i=0}^{2}\beta$	$\sum_{i=0}^{4}\beta$	β_0	$\sum_{i=0}^{1}\beta$	$\sum_{i=0}^{2}\beta$	$\sum_{i=0}^{4}\beta$	$\sum_{i=0}^{8}\beta$
Wheat	CS	1.14	1.10	1.42	1.09	1.38	1.66	1.19	1.33	1.81	1.43	1.38	1.41	2.16	1.87	2.72
	FS	1.70	1.74	1.72	1.74	1.74	1.68	1.82	1.78	1.77	1.51	1.88	1.76	1.82	1.43	1.46
Soybeans	CS	.79	.64	1.09	.65	1.12	.83	.67	1.10	.90	1.07	.77	1.17	1.08	1.18	1.10
	FS	1.12	1.18	.88	1.19	.87	.82	1.31	.86	.90	.99	1.33	.82	.82	1.03	1.01
Corn	CS	.41	.16	1.15	.16	1.06	1.32	.41	1.27	1.62	1.98	.93	1.76	2.41	2.18	2.71
	FS	.53	.45	.97	.45	.93	1.00	.74	1.14	1.33	1.11	.97	1.29	1.51	.83	1.31
Feeder Steers	CS	.16	.25	.53	.21	.66	.71	-.003	.46	.59	.68	-.10	.58	.42	.25	.10
	FS	.42	.41	.91	.39	.94	1.15	.27	.85	1.09	1.08	.33	1.03	1.25	1.06	1.11
Slaughter Steers	CS	.13	.20	.84	.22	.90	.42	.25	.87	.36	1.38	.65	1.22	.98	1.84	1.46
	FS	.36	.39	.91	.40	.92	.78	.39	.91	.72	1.09	.53	1.12	.98	1.20	1.06
Fertilizer	CS	-.51	-.60	.10	-.62	.04	.49	-.50	.20	.44	.62	-.42	.40	.60	.57	1.53
	FS	-.31	-.35	.13	-.37	.005	.62	-.24	.22	.77	.49	-.20	.40	.79	.13	.86
Pesticides	CS	-.05	0.05	0.64	0.05	.46	1.09	.06	.51	1.19	.82	.12	.52	1.12	.72	1.19
	FS	-0.02	.04	.46	.04	.36	.67	.05	.44	.78	.52	.06	.46	.71	.38	.70
Petroleum	CS	1.00	1.04	.91	1.07	.90	.61	1.04	1.03	.46	.35	1.23	1.47	.56	-.13	-1.53
	FS	.44	.32	.83	.32	.73	.98	.35	.84	1.06	.83	.27	1.04	.96	.81	.70
Machinery	CS	.10	.06	.27	.05	.40	.13	.04	.37	.09	.34	-.03	.03	-.30	.31	.76
	FS	.12	.10	.26	.09	.32	.24	.09	.26	.17	.37	-.05	.06	-.19	.22	.37

Note:

CS denotes Carter *et al*'s sample from 1975:1 to 1988:2; FS denotes the full sample from 1975:1 to 1999:4.

coefficient estimates. The overall results indicate the cumulative pass-through effects of the exchange rates on prices, although a zero pass-through is possible. In the two-lag model over the full sample, there is a pass-through of 0.75 or more for wheat, soybeans, corn, livestock, and petroleum. Pass-through occurs to a less extent for fertilizer (0.62) and pesticides (0.67), and there is essentially no pass-through for farm machinery. Models with shorter lags generally give weaker evidence for the LOP for non-farm produced inputs fertilizer, pesticides, and petroleum, since the pass-through effects increase over six months. The pass-through on farm machinery is characterized differently, the greatest pass-through parameter is 0.37 in the models with four and eight lags, suggesting that the price adjustment process is incomplete even after two years.

When comparing between Carter *et al* sample and the full sample, we find that in the two-lag model, the total exchange rate pass-through for wheat, livestock, fertilizer, petroleum, and farm machinery becomes greater when the Carter *et al*'s original sample is extended by eleven years. As noted earlier, in the full sample the contemporaneous coefficient estimate for wheat implies a more than proportionate effect of a change in the exchange rate on prices.[6] The soybean data show a complete pass-through (1.19) contemporaneously over the full sample, while not over Carter *et al* sample (0.65) in the two-lag model. The corn and pesticide data present less pass-through over the full sample than Carter *et al* sample. Overall, the average deviation from the LOP is 0.38 for Carter *et al* sample, but only 0.25 for the full sample. Thus, evidence in favor of the LOP are somewhat stronger in the longer sample.

The Durbin-Watson statistic and Akaike Infomation Criterion and Schwarz Criterion are presented in table 3-2 through 3-4. The Durbin-Watson statistic (DW) is a test for first-order serial correlation, measuring the linear association between adjacent residuals from a regression model. As a rule of thumb, if there is no serial correlation, the DW statistic will be around two. If the DW is less than two, there is evidence of

[6] Recursive regressions for wheat prices covering 1975-99 were conducted and the estimate of the coefficient was found quite sensitive to sample period. The estimate of the contemporaneous coefficient initially rises from 0.91 in 1976:1 to a peak of 1.63 in 1977:2, then falls close to the LOP until the end of Carter *et al*'s sample (1988). Then the estimate steadily increases again up to the end of our sample (1999), peaking at 1.72 in 1998:4.

positive serial correlation. In the presence of negative correlation, the statistic will lie somewhere between two and four.

The Akaike Information Criterion (AIC) is often used as a guide in model selection for choosing the appropriate length of a lag distribution. Smaller values of the AIC are preferred. The AIC is computed as

$$AIC = T\, ln(\text{residual sum of squares}) + 2n$$

where n is number of parameters estimated, T is number of usable observations. In the above tables, the AIC values of model lagged two quarters are the lowest in seven cases out of nine, compared with AIC's in the other two models. The AIC's of slaughter steer and fertilizer prices are the smallest in the four and eight-lag models, respectively.

The Schwarz Criterion (SC) is an alternative to the AIC that imposes a larger penalty for additional coefficients. The SC is calculated as

$$SC = T\, ln(\text{residual sum of squares}) + n\, ln(T)$$

Lower values of the SC are also preferred. Among the three model specifications, those having smallest AIC values also present the lowest SC's with an exception of slaughter steers, which has the lowest AIC in the four-lag model and SC in the two-lag model.[7]

F-tests are also performed for different lag length for the hypothesis that the extra lagged effects are zero. The *p*-values for models with one versus zero, two versus zero, four versus two, and eight versus four lags are shown in table 3-8. If the null hypothesis of the lagged variables equal zero cannot be rejected, i.e., the lagged pass-through is statistically insignificant, then those lagged exchange rates could be dropped out of the model specification. As reported in table 3-8, the null hypothesis of insignificance in the two-lag model over the full sample can not be rejected for all commodities but feeder steers, fertilizer and pesticides. In the one-lag model, there is one more rejection for slaughter steers. In the four and eight-lag models, the fifth to the

[7] The AIC's and SC's of the one-lag model regressions are also obtained. For wheat (AIC is –2.863160, SC –2.784028), corn (AIC –2.180799, SC –2.101667), soybeans (AIC –2.627529, SC –2.548397), slaughter steers (AIC –3.485370, SC –3.406238) and petroleum (AIC –2.428787, SC –2.348139), the values of AIC and SC are even lower than the two-lag model. For feeder steers, pesticides, and farm machinery, the two-lag model still has the lowest values of AIC and SC. For fertilizer, the AIC and SC of the eight-lag model are the lowest.

Table 3-8. *P*-values of *F*-tests for Lag Length by Adding Extra Lags

Commodity		1 Lag $H_0: \beta_1=0$	2 Lags $H_0: \beta_1=\beta_2=0$	4 Lags $H_0: \beta_3=\beta_4=0$	8 Lags $H_0: \beta_5=\beta_6=\beta_7=\beta_8=0$
Wheat	CS	.43	.57	.21	.56
	FS	.94	.98	.72	.53
Soybeans	CS	.12	.23	.60	.57
	FS	.43	.68	.42	.89
Corn	CS	.13	.34	.55	.31
	FS	.28	.58	.42	.79
Feeder Steers	CS	.51	.52	.87	.49
	FS	.05*	.04*	.76	.61
Slaughter Steers	CS	.15	.26	.19	.56
	FS	.04*	.13	.53	.98
Fertilizer	CS	.02*	.02*	.65	.06*
	FS	.04*	.003*	.63	.004*
Pesticides	CS	.04*	.02*	.63	.77
	FS	.01*	.01*	.49	.78
Petroleum	CS	.79	.75	.17	.50
	FS	.23	.48	.90	.37
Machinery	CS	.36	.21	.68	.16
	FS	.20	.19	.45	.20

Notes:

1. CS denotes Carter *et al*'s sample from 1975:1 to 1988:2; FS denotes the full sample from 1975:1 to 1999:4.
2. A single star (*) denotes H_0 is rejected at .05 significance level.

eighth lags for fertilizer are the only ones statistically significant. The findings are consistent with the results in tables 3-5 and 3-7. Models with short lags provide evidence for the LOP to agricultural outputs. For non-farm produced inputs, longer lags are needed to incorporate lagged exchange rate effects and test the LOP hypothesis.

There is also one final issue to address in the extension of testing the Carter *et al* model. Table 3-9 reports Carter *et al*'s original regression results of seasonally adjusted feeder steer prices and the re-estimation over Carter *et al* sample and the full sample. Carter *et al* estimated seasonal dummies for all the commodities but they found seasonal variables were significant only in the feeder steer equation. With seasonal dummies included in their feeder steer regression, Carter *et al* estimated a negative contemporaneous pass-through -0.22 on feeder steer prices. Carter *et al* argued that the beef sector is a different story from others, even though their negative coefficient was not found to be significantly different from zero. Carter *et al* explained that the immediate pass-through on grains and the one-quarter lag effect on fat steer prices reduce the feeding margins when the Canadian dollar devalues. Then the increased feeding costs reduce the prices of feeder steers, which is consistent with a negative contemporaneous pass-through on feeder steer prices (Carter, Gray and Furtan 1990, p.741).

The re-estimation suggests that the story on the beef sector is not consistent with Carter *et al*'s interpretation. As shown in table 3-7, corn and slaughter steers both get one-quarter lag pass-through over either Carter *et al* sample or the full sample. Soybeans get a one-quarter lag pass-through over Carter *et al* sample but an immediate pass-through over the full sample. And in table 3-9, the contemporaneous pass-through on seasonally adjusted feeder steer prices over either sample are both positive numbers 0.37 and 0.50, respectively. Neither re-estimating nor extending the sample yields a negative contemporaneous pass-through on feeder steer prices. The feeder steer sector seems not to be adversely affected by devaluations in the Canadian dollars as in Carter *et al*'s analysis. The results with seasonal dummies do not indicate substantial changes to the basic results on the exchange rate compared to models without seasonal variables. But the evidence for the LOP over the full sample is a little stronger than that of Carter *et*

Table 3-9. Regression Results of Seasonally Adjusted Feeder Steer Prices in the Two-Lag Model

Sample	β_0	β_1	β_2	D_1	D_2	D_3
	t-stat for H_0: $\beta_0=0$	*t* -stat for H_0: $\beta_1=0$	*t* -stat for H_0: $\beta_2=0$	*t* -stat for H_0: $D_1=0$	*t* -stat for H_0: $D_2=0$	*t* -stat for H_0: $D_3=0$
Carter *et al*'s original results	-.22	1.0	.28	-.063	.022	-.051
	(.46)	(2.02)**	(.54)	(2.51)**	(.90)	(2.01)**
Our results over Carter Sample	.37	.48	-.001	-.02	.06	-.005
	(1.28)	(1.55)	(-.003)	(-1.51)	(4.50)**	(-.33)
Our results over the full sample	.50	.53	.13	.01	.05	.02
	(2.34)**	(2.37)**	(.58)	(.97)	(4.68)**	(1.85)*

Notes:

1. A single star (*) denotes H_0 is rejected at .10 significance level.

2. A double star (**) denotes H_0 is rejected at .05 significance level.

al's, since the *t*-tests show that the contemporaneous and one-lag pass-though are both statistically significant.[8]

According to their results shown in table 3-9, Carter *et al* also argued that the seasonal variable indicates a strong seasonal pattern for feeder steers that pass-through is greater in the second and fourth quarters of the year than in the first and third quarters.[9] The Carter *et al*'s emphasis on this seasonal effect is not very convincing from the re-estimation, because there is not a consistent season timing pattern of price pass-through on feeder steers. The results show a significant seasonal effect in the second quarter but not the fourth over the Carter *et al* sample, and significant seasonal effect in the second and third quarters over the full sample.

3.5 Tests of Unit Roots and Cointegration

The purpose of this section is threefold. First, the concept of cointegration and how it is used to test for the LOP as a long-run equilibrium relationships are briefly explained. Second, unit root tests are conducted to see if the series used in Carter *et al* and this study appear to be nonstationary, such that the correct model specification is differences of the series. Third, tests for cointegration are undertaken to determine if there is information in estimating cointegration of levels of price series, which is omitted from a model in differences. Any cointegrating coefficients are estimated to evaluate whether they correspond to the equilibrium condition of the LOP.

3.5.1 Cointegration: A Brief Discussion with Application to the LOP

Testing for the existence of cointegration among economic variables is an increasingly widespread approach to study economic relationships, since the theory of cointegration gives a way to reconcile findings of nonstationarity of individual series with

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[8] Seasonal dummy effects were also estimated for other commodities, besides feeder steers. Although more evidence of various seasonal effects being significant were obtained for farm outputs, the overall results with seasonal dummies included do not change the inferences drawn from table 3.2 – 3.8 above.

[9] Carter *et al* argued that this seasonal pattern is consistent with the time of year feeders are actively traded: the calves are wintering on feed in the first quarter and then put on grass in the second quarter, they remain on pasture in the third quarter and come off to be fed in the fourth quarter. Hence, they argued that a substantial trade is expected only in the second or fourth quarters of the year. (Carter, Gray and Furtan 1990, p.741-742)

the possibility of testing stationary relationships among the levels of economic variables. Economic theory often suggests that certain pairs or groups of economic variables should be linked by a long-run equilibrium relationship. The term equilibrium, as Granger (1986) stated, "is not used to imply anything about the behavior of economic agents but rather to describe the tendency of an economic system to move towards a particular region of the possible outcome space."(Granger 1986 p.216) Although the variables may drift away from equilibrium for a while, economic forces may be expected to act so as to restore equilibrium. Variables integrated of order one *I*(1) tend to diverge over time (as $n \to \infty$).[10] Thus it might seem that such variables could never be expected to obey any sort of long-run equilibrium relationship. Engle and Granger (1987) demonstrated that even though individual *I*(1) economic series may wander apart through time, there may also exist some linear combination of the variables that, over time, converges to an equilibrium. That is, it is possible for two or more variables to be *I*(1) and yet for certain linear combinations of those variables to be stationary, i.e. *I*(0). If that is the case, the variables are said to be cointegrated.

As an alternative to regression analysis with differenced series, cointegration provides an appropriate framework for testing the LOP. Formally, in our case of testing the LOP between Canada and the U.S., the cointegrating regression model takes the form:

$$P_t^1 = C + \alpha P_t^2 + \mu_t \tag{3.5}$$

where P_t^1 and P_t^2 are prices of a specific commodity at time t in two countries Canada and the U.S., expressed in the common currency \$CN. C and α denote parameters to be estimated and μ_t is the residual term.

If P_t^1 and P_t^2 are each nonstationary and *I*(1), but their combination in (3.5) produces a residual series μ_t that is stationary, P_t^1 and P_t^2 are cointegrated with cointegrating vector (1, α), implying a long-run parity relationship whereby deviations from this relationship may occur in the short run with a stable mean of zero. If α = 1, this cointegrating relationship corresponds to the LOP.

[10] A time series, y_t, which is nonstationary and requires *d* differencing transformations to be stationary is said to be integrated of order d, denoted *I*(*d*).

Cointegration is relevant when the individual economic series are integrated of order one. In other words, the data should be stationary in their first differences but not in levels. Therefore, individual series must be examined to determine their orders of integration prior to applying cointegration tests. The Augmented Dickey-Fuller (ADF) test proposed by Dickey and Fuller (1979) is utilized to test for unit roots. The ADF test controls for higher-order correlation in the series by incorporating lagged difference terms of the dependent variable in the regression. To test for a unit root against a deterministic time trend, the ADF test is based on an OLS-estimated equation:

$$\Delta y_t = \delta + \theta t + \lambda y_{t-1} + \gamma_i \sum_{i=1}^{p} \Delta y_{t-i} + \varepsilon_t \qquad (3.6)$$

where Δ is the difference operator, y_t is the variable being tested, δ, θ, λ, and γ_i are parameters to be estimated, p is the number of lagged changes in Δy_t, and ε_t is an error term. In this specification $\lambda = \sum_{i=0}^{p} \gamma_i - 1$, and the equation is used to test:

H_0: $\lambda = 0$, H_1: $\lambda < 0$

The null hypothesis is that the autoregressive representation of the series contains a unit root. This hypothesis is tested against the alternative that the autoregressive representation is stationary around a linear time trend. The result of interest from estimating equation (3.6) is the value of the *t*-ratio associated with the lagged level term λ. If this *t*-ratio is numerically less than the critical value, then the null hypothesis of a unit root (nonstationarity) is rejected and it is concluded that the series does not have a unit root. On the other hand, if the calculated *t*-ratio is numerically larger than the critical value, then the null hypothesis is not rejected and it is concluded that the series is nonstationary and has a unit root. An important feature of this test procedure is that the asymptotic distribution of the *t*-statistic on λ is independent of the number of lagged first differences included in the ADF regression. The *t*-ratio does not have the standard student's *t* distribution, instead it has the Dickey-Fuller distribution.

After estimating equation (3.6) on levels of the series, if there is evidence of a unit root, a first-differenced version of (3.6) excluding the deterministic trend term θt is estimated to determine if the series are stationary in changes. Again, if the *t*-ratio on the lagged change term is numerically less than the critical value, then the hypothesis of a unit root is rejected. If the series does not have a second unit root, it is characterized as nonstationary and integrated of order one $I(1)$. The analysis then proceeds to the test for cointegration between/among the nonstationary series.

The empirical test for cointegration described here follows Engle-Granger test, which is a two-stage procedure, testing for unit roots in the residuals from cointegrating regressions. In the first stage, the cointegrating regression, given in (3.5) above is estimated by OLS. Two cointegrating regressions are formed: first, Canadian prices in \$CN ($P_t^{c,\$CN}$) are regressed on the U.S. prices in \$CN ($P_t^{u,\$CN}$), then the order is reversed, with $P_t^{u,\$CN}$ the dependent variable and $P_t^{c,\$CN}$ the regressor. In the second stage, the residuals from the cointegrating regressions, μ_t, are retrieved and an ADF test is carried out on the residuals for a unit root, versus an alternative of stationarity with mean zero and no time trend. If the null of a unit root is rejected, then the residuals are concluded to be stationary from a cointegration relationship. Otherwise, if the unit root hypothesis can not be rejected, then cointegration does not occur between the prices.

3.5.2 Empirical Results of Unit Root Tests

The exchange rate data and each of the price series used in this study are tested for unit roots over the full sample period 1975-1999. Tests to determine the stationarity characteristics of the individual exchange rate and price series are summarized in table 3-10, where the ADF test-statistics on the levels of individual series are reported for $P^{u,\$US}$, $P^{u,\$CN}$, and $P^{c,\$CN}$, respectively. The regressions to test for a unit root are based on equation (3.6) with different lengths of lagged terms: zero, one, two, and four. Models with the lowest AIC and SC values are shown in the last two columns of the table.

As shown in table 3-10, the results generally tend to suggest nonstationarity of the series in levels with a few exceptions. Generally speaking, except soybean prices which seem to be stationary, most other commodities appear to be nonstationary in levels. There is nearly no rejections of a unit root for non-farm produced inputs fertilizer, pesticides, petroleum, and farm machinery, except in two cases of fertilizer prices with four lags. The exchange rate series presents a unit root across all lag lengths. For farm outputs, in contrast, there is somewhat more evidence of stationarity. The null hypothesis of a unit root in the level data is rejected for wheat prices in one case with one lag and

Table 3-10. Unit Root Tests on Levels of Individual Series

Lag Length		0	1	2	4	AIC	SC
Series		ADF Test-statistic					
Wheat	$P^{u,\$US}$	-2.40	-2.61	-2.79	-3.94**	(4)	(0)
	$P^{u,\$CN}$	-2.32	-2.47	-2.40	-3.47**	(4)	(0)
	$P^{c,\$CN}$	-2.83	-3.23*	-2.93	-3.14	(4)	(0)
Soybeans	$P^{u,\$US}$	-3.62**	-3.71**	-3.59**	-4.31***	(0)	(0)
	$P^{u,\$CN}$	-3.28*	-3.29*	-3.08	-3.63**	(0)	(0)
	$P^{c,\$CN}$	-3.19*	-3.74**	-2.93	-3.48**	(4)	(0)
Corn	$P^{u,\$US}$	-3.03	-4.02**	-3.09	-3.33*	(2)	(1)
	$P^{u,\$CN}$	-2.88	-3.79**	-2.74	-2.92	(2)	(1)
	$P^{c,\$CN}$	-3.15	-4.23***	-2.85	-3.47**	(4)	(2)
Feeder Steers	$P^{u,\$US}$	-2.56	-2.44	-2.42	-3.35*	(4)	(0)
	$P^{u,\$CN}$	-2.77	-2.70	-2.64	-3.82**	(4)	(0)
	$P^{c,\$CN}$	-2.35	-2.50	-2.59	-4.16***	(4)	(4)
Slaughter Steers	$P^{u,\$US}$	-3.06	-2.25	-1.70	-2.83	(4)	(4)
	$P^{u,\$CN}$	-3.41*	-2.60	-1.97	-3.00	(0)	(4)
	$P^{c,\$CN}$	-2.83	-2.38	-1.93	-3.57**	(4)	(4)
Fertilizer	$P^{u,\$US}$	-1.80	-2.46	-2.39	-3.43*	(4)	(4)
	$P^{u,\$CN}$	-1.63	-1.93	-1.63	-2.43	(4)	(4)
	$P^{c,\$CN}$	-1.66	-2.02	-1.41	-3.43*	(4)	(4)
Pesticides	$P^{u,\$US}$	-3.06	-2.74	-2.70	-3.95	(4)	(1)
	$P^{u,\$CN}$	-1.56	-1.20	-0.96	-1.88	(4)	(1)
	$P^{c,\$CN}$	-1.57	-1.19	-1.03	-1.85	(4)	(4)
Petroleum	$P^{u,\$US}$	-2.07	-2.11	-1.29	-1.79	(2)	(0)
	$P^{u,\$CN}$	-2.21	-2.16	-1.48	-1.89	(2)	(0)
	$P^{c,\$CN}$	-1.54	-1.40	-1.32	-1.84	(0)	(0)
Machinery	$P^{u,\$US}$	-1.78	-1.75	-1.49	-2.32	(4)	(4)
	$P^{u,\$CN}$	-0.49	-0.54	-0.43	-1.62	(4)	(4)
	$P^{c,\$CN}$	-0.87	-1.15	-1.02	-2.11	(4)	(4)
Exchange Rate		-1.48	-1.68	-1.78	-2.80	(4)	(0)

Notes:

1. Critical values are from MacKinnon (1994).

2. $P^{u,\$US}$ denotes the U.S. prices expressed in \$US.
   $P^{u,\$CN}$ denotes the U.S. prices expressed in \$CN.
   $P^{c,\$CN}$ denotes Canadian prices expressed in \$CN.

3. A single star (*) denotes statistically different from zero at the .10 significance level.
   A double star (**) denotes statistically different from zero at .05 significance level.
   A triple star (***) denotes statistically different from zero at .01 significance level.

4. The numbers in brackets denote the lag length in the model which shows the lowest values of AIC and SC among various lag lengths.

two cases with four lags. Soybean prices show evidence of stationarity with different lag lengths. A unit root is rejected for corn prices with one lag and two cases with four lags. The unit root is rejected with four lags in all three cases for feeder steers and one case for slaughter steers.

Taking model selection criterion AIC and SC into account, the assessment of nonstationarity is somewhat re-enforced. If the zero-lag model is chosen according to lower SC's, then all wheat series support nonstationarity. Likewise, for corn prices, if the two-lag model is selected by AIC or SC criteria, then all series appear to be nonstationary. Overall, models with long lags (four) tend to have the lowest values of AIC, and models with short lags (even zero) tend to have the lowest values of SC. The four-lag model seems to be the most appropriate specification for fertilizer and farm machinery prices, since it presents the lowest AIC's and SC's in each case.

Since most of the series present a single unit root, the next step is to test if the series have a second unit root by examining stationarity of the first-differenced series. As reported in table 3-11, the results unanimously reject the hypothesis of a unit root at a 5% significance level for wheat, soybeans, corn, feeder steers, slaughter steers, fertilizer, petroleum, and the exchange rate series across all lag lengths, since the reported ADF *t*-ratios are numerically below the critical values. Therefore, each series of these commodities is characterized as integrated of order one $I(1)$. For pesticides and farm machinery, a second unit root is rejected with zero, one, and two lags, but not in the four-lag model.

3.5.3 Empirical Results of Tests for Cointegration and the LOP

Tests for cointegration between Canadian and the U.S. prices, both expressed in Canadian dollars, are summarized in table 3-12. For each test, the null hypothesis is no cointegration and the residuals contain a unit root. The alternative hypothesis is that the variables in the corresponding regression are cointegrated and the residual series is stationary. Tests are conducted with each price, respectively, as the dependent variable, and with zero, one, two, and four lags.

Table 3-11. Unit Root Tests on First-Differenced Individual Series

Lag Length		0	1	2	4
Series		ADF Test-statistic			
Wheat	$P^{u, \$US}$	-9.32**	-6.66**	-5.29**	-4.71**
	$P^{u, \$CN}$	-9.55**	-7.14**	-5.40**	-4.63**
	$P^{c, \$CN}$	-8.93**	-7.57**	-5.15**	-4.99**
Soybeans	$P^{u, \$US}$	-10.39**	-7.64**	-5.93**	-5.54**
	$P^{u, \$CN}$	-10.43**	-7.76**	-5.77**	-5.42**
	$P^{c, \$CN}$	-9.14**	-8.45**	-5.79**	-5.24**
Corn	$P^{u, \$US}$	-8.03**	-8.39**	-5.79**	-5.39**
	$P^{u, \$CN}$	-8.08**	-8.71**	-5.87**	-5.42**
	$P^{c, \$CN}$	-8.00**	-9.28**	-6.02*	-5.57**
Feeder Steers	$P^{u, \$US}$	-8.76**	-6.61**	-4.19**	-5.20**
	$P^{u, \$CN}$	-8.96**	-6.90**	-4.19**	-5.32**
	$P^{c, \$CN}$	-8.87**	-6.75**	-3.89**	-4.95**
Slaughter Steers	$P^{u, \$US}$	-11.85**	-10.21**	-7.46**	-4.13**
	$P^{u, \$CN}$	-11.91**	-10.90**	-7.40**	-4.47**
	$P^{c, \$CN}$	-11.60**	-9.65**	-5.42**	-4.70**
Fertilizer	$P^{u, \$US}$	-8.42**	-6.36**	-4.25**	-3.69**
	$P^{u, \$CN}$	-8.58**	-7.36**	-4.60**	-3.82**
	$P^{c, \$CN}$	-7.96**	-9.18**	-4.71**	-2.79**
Pesticides	$P^{u, \$US}$	-15.76**	-8.08**	-6.02**	-2.80*
	$P^{u, \$CN}$	-12.00**	-7.75**	-5.10**	-2.50
	$P^{c, \$CN}$	-10.20**	-7.49**	-5.26**	-2.39
Petroleum	$P^{u, \$US}$	-9.71**	-9.47**	-5.40**	-4.26**
	$P^{u, \$CN}$	-9.98**	-9.53**	-5.65**	-4.66**
	$P^{c, \$CN}$	-10.72**	-6.84**	-4.43**	-3.62**
Machinery	$P^{u, \$US}$	-10.18**	-7.41**	-5.10**	-2.43
	$P^{u, \$CN}$	-9.14**	-6.64**	-3.37**	-2.45
	$P^{c, \$CN}$	-7.52**	-6.79**	-4.03**	-1.76
Exchange Rate		-8.12**	-5.89**	-3.56**	-3.17*

Notes:

1. Critical values are from MacKinnon (1994).

2. $P^{u, \$US}$ denotes the U.S. prices expressed in \$US.
   $P^{u, \$CN}$ denotes the U.S. prices expressed in \$CN.
   $P^{c, \$CN}$ denotes Canadian prices expressed in \$CN.

3. A single star (*) denotes statistically different from zero at the .05 significance level.
   A double star (**) denotes statistically different from zero at .01 significance level.

Table 3-12. Cointegration Test Results

	Dependent Variable							
	$P^{c, \$CN}$				$P^{u, \$CN}$			
Regressor	$P^{u, \$CN}$				$P^{c, \$CN}$			
Lag Length	0	1	2	4	0	1	2	4
Wheat	-3.10*	-3.28**	-3.68**	-3.28**	-3.03*	-3.06*	-3.60**	-3.64**
Soybeans	-8.25***	-5.21***	-3.89***	-2.31	-8.35***	-5.16***	-3.90***	-2.49
Corn	-5.99***	-5.81***	-4.40***	-4.09***	-5.83***	-5.45***	-4.13***	-3.68**
Feeder Steers	-5.88***	-4.74***	-4.08***	-4.43***	-6.05***	-4.97***	-4.25***	-4.40***
Slaughter Steers	-6.91***	-5.11***	-3.33**	-3.01*	-7.03***	-5.10***	-3.26**	-2.70
Fertilizer	-3.96***	-4.10***	-2.96*	-3.18**	-3.78***	-3.77***	-2.49	-2.65
Pesticides	-1.39	-1.53	-1.12	-1.81	-1.12	-0.85	-0.34	-1.34
Petroleum	-3.68**	-2.86	-2.22	-2.27	-3.89***	-3.16*	-2.42	-2.57
Machinery	-2.32	-2.15	-1.73	-2.29	-2.18	-1.98	-1.47	-2.12

Notes:

1. Critical values are taken from Engle and Granger (1987). Critical values for T = 100 are -2.91 at 10% significance level, -3.17 at 5% significance level, -3.73 at 1% significance level. (Engle and Granger (1987, p.270)
2. $P^{c, \$CN}$ denotes Canadian prices expressed in \$CN.
   $P^{u, \$CN}$ denotes the U.S. prices expressed in \$CN.
3. A single star (*) denotes H_0 is rejected at .10 significance level.
   A double star (**) denotes H_0 is rejected at .05 significance level.
   A triple star (***) denotes H_0 is rejected at .01 significance level.

As shown in table 3-12, the unit root tests on residuals from the cointegrating regressions support cointegration for wheat, corn, feeder steers, and slaughter steers in each case of either regression direction. For these commodities, nonstationarity of the residual series is rejected at the 0.01 and 0.05 level. Cointegration is not supported for pesticide and farm machinery prices between Canada and the U.S., since a unit root cannot be rejected in each case with various lag lengths. Soybean prices show evidence of cointegration in the zero, one, and two-lag model, but not with four lags. Cointegration is supported for fertilizer in the zero, one, and four-lag model, while the results are less conclusive with two lags since a unit root is not rejected at the 0.10 level for one direction. For petroleum, short lag models (zero and one) present cointegration in either direction, but models with two or four lags do not. Thus, it appears that a long-run equilibrium relationship holds for wheat, corn, soybeans, feeder steers, slaughter steers, and fertilizer between the price levels in the two countries. The evidence is somewhat ambiguous for petroleum, but the zero-lag model that supports cointegration for petroleum prices has the lowest value of SC. Although the AIC from the zero-lag model is not the smallest (6.458), its difference to the lowest AIC (6.456), which is derived from the two-lag model, is small. Pesticide and farm machinery prices appear to be nonstationary and not cointegrated, the series may not be trending together and may not obey a long-run relationship.

Strict adherence to the LOP requires not only that the two prices are cointegrated, but also that the cointegrating parameter equals one in these regressions. Table 3-13 shows the estimates of cointegrating vectors from the two cointegrating regressions for prices between Canada and the U.S. The estimated cointegrating parameter $\hat{\alpha}$ for agricultural outputs wheat, soybeans, corn, feeder steers, and slaughter steers are quite close to unity for the regressions in either direction, providing evidence in favor of the LOP. However, those for non-farm produced inputs fertilizer and petroleum are somewhat far from one, suggesting the long-run relationships between the levels of these prices are less than proportional.

As a final test, the cointegrating parameter α is restricted to unity in the cointegrating regressions and then the residuals are re-tested for unit roots. The results are reported in table 3-14. Since the evidence in table 3-12 show that pesticide and farm

Table 3-13. Cointegrating Regressions and Vectors for Prices between Canada and the U.S.

	Dependent Variable					
	$P^{c, \$CN}$			$P^{u, \$CN}$		
Regressor	$P^{u, \$CN}$			$P^{c, \$CN}$		
Commodity	$\hat{\alpha}$	*t*-Statistic	R^2	$\hat{\alpha}$	*t*-Statistic	R^2
Wheat	1.09	19.78	0.80	0.74	19.78	0.80
Soybeans	0.96	47.48	0.96	0.99	47.48	0.96
Corn	0.99	29.93	0.90	0.91	29.93	0.90
Feeder Steers	0.90	57.94	0.97	1.08	57.94	0.97
Slaughter Steers	0.83	52.27	0.97	1.16	52.27	0.97
Fertilizer	0.59	31.31	0.91	1.55	31.31	0.91
Pesticides	0.67	26.90	0.88	1.33	26.90	0.88
Petroleum	0.59	25.70	0.87	1.47	25.70	0.87
Machinery	0.51	62.55	0.97	1.92	62.55	0.98

Notes:

1. $P^{c, \$CN}$ denotes Canadian prices expressed in \$CN.

2. $P^{u, \$CN}$ denotes the U.S. prices expressed in \$CN.

Table 3-14. Cointegration Tests after $\hat{\alpha}$ is Restricted to One

	Dependent Variable							
	$P^{c, \$CN}$				$P^{u, \$CN}$			
Regressor	$P^{u, \$CN}$				$P^{c, \$CN}$			
Lag Length	0	1	2	4	0	1	2	4
Wheat	-3.05*	-3.31**	-3.58**	-3.13*	-3.05*	-3.31**	-3.58**	-3.13*
Soybeans	-8.40***	-5.21***	-3.94***	-2.49	-8.40***	-5.21***	-3.94***	-2.49
Corn	-6.04***	-5.83***	-4.41***	-4.08***	-6.04***	-5.83***	-4.41***	-4.08***
Feeder Steers	-5.73***	-4.76***	-4.00***	-3.65**	-5.73***	-4.76***	-4.00***	-3.65**
Slaughter Steers	-5.52***	-3.58***	-2.28	-1.61	-5.52***	-3.58**	-2.28	-1.61
Fertilizer	-1.83	-1.42	-0.55	-1.04	-1.83	-1.42	-0.55	-1.04
Petroleum	-3.20**	-2.86	-2.30	-2.57	-3.20**	-2.86	-2.30	-2.57

Notes:

1. Critical values are taken from Engle and Granger (1987). Critical values for T = 100 are -2.91 at 10% significance level, -3.17 at 5% significance level, -3.73 at 1% significance level. (Engle and Granger (1987, p.270)

2. $P^{c, \$CN}$ denotes Canadian prices expressed in \$CN.
   $P^{u, \$CN}$ denotes the U.S. prices expressed in \$CN.

3. A single star (*) denotes H_0 is rejected at .10 significance level.
   A double star (**) denotes H_0 is rejected at .05 significance level.
   A triple star (***) denotes H_0 is rejected at .01 significance level.

machinery prices are not cointegrated, they are dropped out of table 3-14 of the re-test for cointegration. As shown in table 3-14, the results for this restricted model are generally similar to those shown for the unrestricted model in table 3-12 for wheat, soybeans, corn, feeder steers, and petroleum. Cointegration is supported for wheat, corn, and feeder steers with various lag lengths no matter which way the regression is run, suggesting these prices in Canada and the U.S. are cointegrated when the proportionality restriction is imposed. For fertilizer prices, the null of no cointegration cannot be rejected for the restricted models. For slaughter steers and petroleum, evidence of cointegration is weaker in the restricted model. Cointegration is supported for slaughter steers at the 0.01 level of significance in the restricted models with zero or one lag, but not even at the 0.10 level of significance in the two-lag and four-lag models.

3.6 Discussion of the Results

The statistical tests conducted in this study indicate that the LOP holds up weakly for non-farm produced inputs in Canada and the U.S. Since Canadian and the U.S. markets have become more integrated under NAFTA, there are few trade barriers and transportation costs are relatively low between the two markets, it is interesting to discuss why the input prices do not fully adjust to changes in the exchange rate. Deviation from the LOP for input prices may be caused by the following three factors.

First, all the input prices used in this study are aggregated indexes. Consequently, the aggregation problem with these index numbers appears when the products being applied in Canadian agriculture differ from their U.S. counterparts. For an example, the fertilizer indexes are aggregated from prices of various types of fertilizer including nitrogen fertilizer, mixed fertilizer, and potash and phosphate materials. The pesticide indexes are aggregated from prices of herbicides, insecticides, fungicides and etc. The petroleum indexes are aggregated from prices of diesel fuel, gasoline, and LP gas. In addition, if the price series is a Laspeyres index by using a fixed basket of products, it does not account for the substitution of alternative goods and thus overstates the impact on farmers of the price increase in one type of products among the basket. In contrast, if the price is a Paasche index which takes into account of substitutes, it understates the impact of price increase on farmers since the reduction in farmer's welfare is not reflected.

Second, as Carter and Hamilton (1989) argued, government regulation, varying levels of product differentiation, and the lack of competitive forces might contribute to price differences of inputs for wheat production between Canada and the U.S. Meanwhile, the divergence in petroleum products can be explained by government intervention in the pricing of these products.

Carlson *et al* (1999) investigated the pesticide price differentials between Canada and the U.S. Their study was initiated by the concern during recent years that prices for identical pesticide products were higher in North Dakota and Minnesota in the U.S. than in the prairie provinces of Canada, which in general are two areas with similar climates and technology. The restriction in the movement of pesticides across country borders is one of the basic reasons for the price differential. A few other factors sometimes are involved, including different patent expiry dates of products, different market sizes, different costs to provide pesticide products in different locations, different preferences of farmers, different willingness of farmers to pay for products, and different numbers of substitute products available. From a manufacturer's perspective, the U.S. and Canada represent two distinct markets for pesticide sales. In addition, pesticide manufacturers consider the pest control demand from other locations and crops in pricing their products.

Third, the LOP is violated for farm machinery prices. This result is consistent with previous analyses in the LOP literature which focused on industrial goods and found stickiness in their price adjustment (Isard 1977, Crouhy-Veyrac *et al* 1982, Carter and Hamilton 1989, and Ceglowski 1994). Additionally, Carter *et al* (1990) gave some specific reasons for the lack of exchange rate pass-through on farm machinery prices. They indicated that unable to have the machinery serviced by the local dealer in the event of a breakdown precludes farmers in one country from purchasing the machinery in the other country is one of the reasonable explanations.

3.7 Summary and Conclusions

In this chapter, dynamic econometric models were developed to estimate the exchange rate pass-through effects on agricultural prices and examine the validity of the LOP hypothesis for five major outputs and four non-farm produced inputs in Canadian and U.S. agriculture. The estimation framework is constructed upon Carter *et al*'s 1990 paper with similar data, but extended by adding eleven years to Carter *et al*'s sample period and additional price series (corn) to the estimation. In addition, various lag lengths are included in the model specification, besides the original two lags in Carter *et al*'s model, in attempting to test the LOP as a short-run, intermediate-run, or medium-run relationship. Graphical evidence indicate a tendency for prices of the five agricultural outputs in Canada and the U.S., when expressed in the same currency, to move closely together, which is supportive of the LOP. The visual evidence is less supportive of the LOP for non-farm produced inputs. In particular, for pesticides and petroleum, the price series do not exhibit persistent close movement. And the price series of farm machinery appear to diverge from the LOP.

The empirical analysis consists of three parts. The first part in section 3.3 contains Carter *et al*'s original regression estimation results and our interpretation of the exchange rate pass-through and the LOP based on their evidence. In the second part, Carter *et al*'s analysis is replicated using similar data and extended with alternative lag lengths. These regression results are presented and examined in section 3.4. Finally, stationarity and cointegration of the price series are tested to investigate the LOP as a long-run equilibrium relationship.

The econometric results indicate that the LOP holds for agricultural outputs, and to a less extent for non-farm produced inputs, as first reported by Carter *et al*. In particular, the new empirical evidence from regression analysis support the LOP as applied to basic homogeneous farm outputs wheat, soybeans, corn, and livestock (feeder steers and slaughter steers). The LOP holds to a less extent for three non-farm produced inputs (fertilizer, pesticides and petroleum), and their adjustment time for the price convergence to the LOP is longer than that of farm outputs. The LOP is violated for farm machinery and the exchange rate pass-through effects are small. Thus, our hypotheses in chapter 1 are supported, that is, within a short time, i.e. three to six months, there is a complete exchange rate pass-through for agricultural outputs. For non-farm produced inputs, more time is required than for farm outputs to capture the lagged effects of the exchange rate changes. This suggests that a fall in the Canadian dollar would not cause all input prices in Canada to increase by the full extent of the exchange rate change, which would give Canadian farmers comparative advantages on the input cost side.

The extension of Carter *et al* sample with eleven years gives rise to somewhat stronger evidence for the LOP validity than the original sample. In the two-lag model of Carter *et al*, the average deviation from the LOP (excluding farm machinery) decreases from 0.38 over their sample to 0.25 over our full sample. The econometric results from models incorporating various time lags indicate that the intermediate-run (four lags) and medium-run (eight lags) models do not yield much changes to the basic results derived from the short-run (two lags) model, none do seasonal effects change the basic results. The optimal lag length for the estimation model specification is determined by a combination of various criteria. The optimal lag length seems to be two lags for most of the commodities studied: wheat, soybeans, corn, feeder steers, slaughter steers, pesticides, petroleum and farm machinery. For fertilizer prices, the optimal lag length is eight quarters.

Finally, in order to further explore the LOP validity as a long-run relationship, in section 3.5, time series properties are examined for the exchange rate and prices of the nine agricultural outputs and inputs. The ADF test is undertaken for the number of unit roots in the series. Prices of farm outputs wheat, corn, feeder steers, slaughter steers, and the non-farm produced inputs fertilizer, pesticides, petroleum, and farm machinery appear to be nonstationary and integrated of order one $I(1)$. Soybean price series seem to be stationary. Cointegration is then tested between Canadian and U.S. prices, when expressed in a common currency. The Engle-Granger test indicates that prices of most of the commodities being considered (wheat, soybeans, corn, feeder steers, slaughter steers, fertilizer, and petroleum) are cointegrated, implying that these prices tend to return to a stationary equilibrium relationship. But pesticide and farm machinery prices are not cointegrated, thus there does not appear to be a long-run equilibrium relationship for these series. The estimates of cointegrating vectors provide evidence of adherence to the LOP in the long run, particularly for farm outputs. Residuals from cointegrating regressions are stationary for the five farm outputs when the cointegrating coefficient is restricted to unity, as implied by the LOP.

In all, the empirical evidence from the regression analysis and cointegration tests are supportive of the LOP for the five agricultural outputs and three of four non-farm produced inputs of Canada and the U.S. being considered. Exchange rate changes tend to display longer lagged effects for non-farm produced inputs than outputs. The LOP is violated for farm machinery prices, which deviate from the parity equilibrium not only in the short to medium run, but also in the long run.

Chapter IV – Summary and Conclusions

This study addressed the issue of price behavior due to exchange rate movements in the U.S. and Canadian markets for major agricultural outputs and non-farm produced inputs. The effects of exchange rate changes on the relative prices of five outputs (wheat, soybeans, corn, feeder steers, and slaughter steers) and four inputs (fertilizer, pesticides, petroleum, and farm machinery) were investigated by examining the empirical validity of the LOP, hypothesizing that within a short period, there is a complete exchange rate pass-through on agricultural output and traded non-farm produced input prices, but the lagged adjustment time of inputs to the exchange rate changes is longer than that of outputs.

The theoretical framework in which to analyze the exchange rate effects on prices and production was illustrated in chapter 1. A currency devaluation would increase farm output prices, but its impact on supply also depends on input price changes. If all the inputs in production are traded and there is a complete exchange rate pass-through, supply would remain unchanged, since input prices would rise as much as the exchange rate changes, offsetting output price increases. If none of the inputs are traded, then there is no exchange rate pass-through on inputs, and the increase in output prices and supply will fully reflect the extent of the depreciation. In a case that not all inputs are traded or their exchange rate pass-through effects are incomplete, supply would be decided by a combination of factors including the elasticity of the supply curve, the proportion of traded inputs in production and responses to changes in their prices.

Chapter 1 also contains a brief introduction of the development of Canadian agriculture and its bilateral trade relationship with the U.S. The concept of flexible exchange rates and the $CN/$US movement since the breakdown of Bretton Woods System were described. The Canadian dollar presents two periods of depreciation against the U.S. dollar: 1973-86 and 1991-99. Thus it is of interest to investigate the pass-through effect of the exchange rate fluctuations on agricultural prices and assess whether output and input prices between the two countries function according to the LOP.

Chapter 2 contains an introduction to the theory of the LOP, which states that commodity arbitrage ensures that each commodity has a single price, defined in a common currency unit, throughout the world. The LOP is an important building block in theories of international economics and also has been capturing attention of applied economists for a long time. An overview of the existing empirical literature as well as a review of several studies closely relating to the LOP in the particular U.S. and Canadian agricultural trade markets were also provided in chapter 2. Although the effects of exchange rate changes on agricultural outputs have been extensively studied, the issue of the impacts on traded non-farm produced inputs has not been explored as much. In general, previous empirical literature provides mixed results about adherence to the LOP. Various econometric techniques have been employed to test the LOP. In addition to regression analysis, which is a widely used testing method for the LOP, cointegration analysis is utilized as an alternative approach in many recent studies. From the perspective of the data used, some studies were conducted at an aggregate level with general price indexes and some utilized data of individual commodities at a disaggregate level. Several studies focused on the LOP in the markets for traded agricultural commodities between the two close and integrated economies of the U.S. and Canada.

In chapter 3, econometric models for testing the LOP were developed and then applied in an empirical evaluation of the LOP in Canadian and U.S. markets for traded agricultural commodities. The basic dynamic model was constructed upon Carter *et al*'s 1990 paper. The empirical applications involved three components. The first segment considered Carter *et al*'s original application of the regression model for testing the LOP. In the second segment, Carter *et al*'s regression analysis was extended using similar data to a longer sample period, and various time lags were incorporated in the estimation specifications to detect the possible lag effects in the adjustment of prices to exchange rate changes. An addition, one more commodity (corn) was included in the estimation. The different lags allowed on exchange rates provide a basis for determination of the speed at which changes in currency value are transmitted to commodity prices. The empirical results of this model extension indicate that for the nine commodities and time periods examined, the LOP holds for the five agricultural outputs, to a less extent for three non-farm produced inputs, and is refuted for one input (farm machinery). For non-farm produced inputs, the lagged pass-through effects of the exchange rate fluctuations tend to be longer than that of outputs. The evidence obtained is somewhat stronger in favor of the LOP over the full sample (1975-99) than Carter *et al* sample (1975-88).

In the third segment, the empirical analysis was widened to consider the stationarity properties of the time series used in estimation. The ADF tests failed to reject a unit root in autoregressive models of the individual series for the exchange rate and eight of nine commodity prices, implying that it was correct to first-difference the nonstationary $I(1)$ series in the estimation models. Cointegration between prices in Canada and the U.S., expressed in a common currency, was then tested in order to investigate whether the prices moved together in a stationary long-run equilibrium. Empirically, prices of the farm outputs and two of the non-farm produced inputs appear cointegrated, with the cointegrating parameter estimates close to unity, particularly for farm outputs. The LOP as a long-run relationship was further examined by imposing proportionality in the cointegrating regressions, and the evidence suggests stationarity of the residuals.

Overall, the empirical results gave rise to supportive evidence in favor of the LOP for selected agricultural outputs in Canada and the U.S. within the time period studied. Slower convergence and somewhat weaker evidence of the LOP emerge for the non-farm produced inputs, and the LOP is violated for farm machinery. This suggests that an exchange rate depreciation does not have full impact on agricultural input markets, and affects output prices to a greater extent. Since the LOP does not hold for all traded inputs, the input prices increase would not completely offset the increase in output prices, such that farmers in the two countries receive different production incentives, as illustrated in figure 1-3 in chapter 1.

This effect is shown in table 4-1, which empirically compares farm output prices relative to farm machinery price indexes in Canada and the U.S. during 1990-91, when the nominal exchange rate \$CN/\$US averaged 1.16, and 1998-99, when the Canadian dollar has depreciated to 1.49 against the U.S. dollar. Farm machinery price indexes are re-scaled to 1990 = 100. Except wheat, the ratios of adjusted Canadian prices relative to adjusted U.S. prices for other farm outputs are close to the exchange rate during 1990-91, suggesting the adherence to the LOP. The depreciation of \$CN against \$US after 1990-91 led to an increase in the nominal prices of Canadian outputs and a

Table 4-1. Relative Prices of Farm Outputs to the Farm Machinery Price Indexes in Canada and the U.S. during Early 1990s and Late 1990s

	1990-91			1998-99						
Commodity	Adjusted Canadian Prices ($CN)	Adjusted U.S. Prices ($US)	Ratio	Nominal Canadian Prices ($CN)	Nominal U.S. Prices ($US)	Canadian Farm Machinery Price Index	U.S. Farm Machinery Price Index	Adjusted Canadian Prices ($CN)	Adjusted U.S. Prices ($US)	Ratio
Wheat	171.17	119.59	1.43	233.41	111.63	140.07	138.96	172.86	80.39	2.05
Soybeans	225.66	207.09	1.09	282.11	195.55	140.07	138.96	218.13	141.02	1.55
Corn	105.45	96.41	1.09	116.59	85.58	140.07	138.96	86.73	61.68	1.41
Feeder Steers	92.55	86.49	1.07	102.98	74.09	140.07	138.96	71.82	53.30	1.35
Slaughter Steers	79.18	75.32	1.05	84.72	63.82	140.07	138.96	59.24	45.91	1.29

Notes:

1. The farm machinery price indexes are re-scaled to 1990 = 100, so the nominal and adjusted prices of farm outputs are nearly equal in 1990-91 period.

2. The price data of farm machinery in 1999 is the index of the first quarter.

decrease in the nominal prices of the U.S. outputs by the 1998-99 period. The farm machinery prices of the two countries rose about 40% and 39%, respectively, during the 1990s. When adjusted (deflated) by the similar increases in farm machinery prices, the output prices mostly fall in both Canada and the U.S. by 1998-99, but fall proportionately more in the U.S. The adjusted price ratios in late 1990s indicate that Canadian farmers' production incentives were improved relative to their U.S. counterparts by the depreciation of the Canadian dollar.

More generally, farmer's incentives to produce may also depend on farm output prices relative to a total index of the goods they consume. Again, if exchange rate changes are not fully passed through to these consumer goods, a depreciation will increase incentives, while an appreciation will reduce incentives. The LOP can be expressed equivalently in nominal or real terms (either as the nominal Canadian price equals the nominal exchange rate times the nominal U.S. price or the deflated Canadian price equals the real exchange rate times the deflated U.S. price, as in p.18). This effect is shown in table 4-2, which compares farm output prices deflated by the overall CPI of Canada and the U.S., respectively, in early and late 1990s. Although there are small variations among the outputs, the ratios of Canadian deflated prices relative to U.S. deflated prices show that except wheat, deflated output prices generally adhered to the LOP in 1990-91, when nominal and real values are essentially equivalent because the CPIs are scaled to 100, and 1998-99, when the real exchange rate is 1.56.[11] Again, the deflated price ratios during 1998-99 imply that production incentives faced by farmers were increased in Canada and reduced in the U.S.

In all, the theory of the LOP plays an important role as a building block in international economics. This study contributes to the broad literature by exploring the LOP not only for prices of agricultural outputs, but also for non-farm produced inputs in two close and integrated economies, where trade of many agricultural goods is relatively free of barriers. The nominal prices of agricultural outputs are found to adjust to the LOP, while the prices of one traded non-farm produced input does not respond to the

[11] The real exchange rate 1.56 = the nominal exchange rate 1.49 * (U.S. CPI 126.09 / Canadian CPI 120.05)

Table 4-2. Inflation-Adjusted Prices of Farm Outputs in Canada and the U.S. during Early 1990s and Late 1990s

	1990-91			1998-99						
Commodity	Deflated Canadian Prices ($CN)	Deflated U.S. Prices ($US)	Ratio	Nominal Canadian Prices ($CN)	Nominal U.S. Prices ($US)	Canadian CPI	U.S. CPI	Deflated Canadian Prices ($CN)	Deflated U.S. Prices ($US)	Ratio
Wheat	168.77	119.39	1.41	233.41	111.63	120.05	126.09	194.57	88.58	2.20
Soybeans	222.46	206.75	1.08	282.11	195.55	120.05	126.09	235.40	155.33	1.52
Corn	104.04	96.24	1.08	116.59	85.58	120.05	126.09	97.22	67.93	1.43
Feeder Steers	91.18	86.36	1.06	102.98	74.09	120.05	126.09	85.76	58.74	1.46
Slaughter Steers	78.05	75.19	1.04	84.72	63.82	120.05	126.09	70.56	50.60	1.39

Notes:

1. The real prices are deflated by CPI scaled to 1990 = 100, so the nominal and real prices of farm outputs are nearly equal in 1990-91 period.

2. Consumer Price Index (CPI) of the U.S. is all items index for all urban consumers, obtained from Bureau of Labor Statistic, U. S. Department of Labor. CPI of Canada is all items index, obtained from Statistics Canada.

exchange rate changes. A real currency depreciation/appreciation would also change prices of traded goods relative to non-traded goods. Accordingly, farmer's incentives to produce tend to be different in the two markets. Particularly in this study, a devaluation in the Canadian dollar against the U.S. dollar in the 1990s makes Canadian farmers receive greater price incentives for production than U.S. farmers, suggesting that Canadian farmers would be relatively better off, at least on account of exchange rate changes alone.

Appendix Table A. Description of Output Commodity Price Data

Commodity	U.S.	Canada
Wheat	No.1, hard red winter wheat, ordinary protein, Kansas City Monthly US$/metric ton Source: Table 22 “Domestic and foreign wheat prices”, *Wheat Situation and Outlook Yearbook*, ERS, USDA	No.1, Canadian western red spring wheat, 13.5% in-store, St. Lawrence Monthly US$/metric ton Source: Table 22 “Domestic and foreign wheat prices”, *Wheat Situation and Outlook Yearbook*, ERS, USDA
Soybeans	No.1 yellow, 30-day, Chicago Monthly $US/bushel Source: Table 18--“Cash Prices, Selected U.S. Commodities”, *Agricultural Outlook*, ERS, USDA	Producer price, Chatham, Ontario Monthly $CN/tonne Source: Statistics Canada, obtained from Mr. Mitch Wensley, Market Analysis Division, AAFC
Corn	No.2 yellow, 30-day, Chicago Monthly $US/bushel Source: Table 18--“Cash Prices, Selected U.S. Commodities”, *Agricultural Outlook*, ERS, USDA	Producer price, Chatham, Ontario Monthly $CN/tonne Source: Statistics Canada, obtained from Mr. Mitch Wensley, Market Analysis Division, AAFC
Feeder Steers	Medium no.1, Oklahoma City Quarterly $US/100lbs 750-800 lb. (Prior to 1992: 700-800 lb.) Source: ERS, USDA	1975-93 Calgary Good feeder steers, Monthly $CN/100lbs *From 1973 to 1975 "good feeder steers" weighed over 750 pounds and from 1976 to 1990 they weighed 800-900 pounds. Source: Table 003-0068, CANSIM II, Statistics Canada 1994-99 Saskatchewan 800-900 lbs Monthly $/100lbs Source: “Monthly Weighted Average Prices on Sales at Public Stockyards”, *Livestock Market Review* 1994-99, AAFC
Slaughter Steers	Choice steers, Texas Quarterly US$/100lbs 1,100-1,300 lb. (Prior to 1986: 900-1,100 lb.) Source: ERS, USDA	1975-93 Winnipeg Monthly $CN/100lbs 1,000lbs and over Source: Table 003-0068, CANSIM II Statistics Canada 1994-99 Manitoba 1,251 lbs and over Source: “Slaughter Cattle-Monthly Weighted Average Prices”, *Livestock Market Review* 1994-99, AAFC

Appendix Table B. Description of Input Commodity Price Data

U.S.	Canada
Fertilizer 1975-96 Quarterly 1997-99 Monthly Index: base 1990-92=100	Fertilizer 1975-99 Quarterly Index: base 1986=100
Agricultural Chemicals 1975-96 Quarterly 1997-99 Monthly Index: base 1990-92=100	Pesticides 1975-99 Quarterly Index: base 1986=100
Fuel 1975-96 Quarterly 1997-99 Monthly Index: base 1990-92=100	Petroleum Products 1975-99 Quarterly Index: base 1986=100
Farm Machinery 1975-96 Quarterly 1997-99 Monthly Index: base 1990-92=100	Machinery Replacement 1975-99 Quarterly Index: base 1986=100
Source: "Prices Paid Indexes: Quarterly and Annual Average", *Agricultural Prices*, NASS, ERS, USDA	Source: Table 328-0001:"Farm Input Price Indexes", CANSIM II, Statistics Canada

Notes:

1.Abbreviations:

NASS = National Agricultural Statistics Service

ERS = Economic Research Service

USDA = United States Department of Agriculture

AAFC = Agricultural and Agri-Food Canada

2.Related websites:

ERS, USDA -- http://www.ers.usda.gov

NASS, ERS, USDA -- http://www.usda.gov/nass

Statistics Canada – http://www.statcan.ca

AAFC -- http://www.agr.ca

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