Co-integration, error correction, and purchasing power parity between Canada and the United States

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Abstract. The concept of co-integration and the associated error-correction representation of a dynamic process (see Engle and Granger 1987) is applied to the purchasing power parity relationship between Canada and the United States. The results are supportive of purchasing power parity (PPP) as a long-run equilibrium relationship between Canadian prices, American prices, and the Canadian dollar / American dollar exchange rate. The PPP relationship is maintained, although with different dynamic mechanisms, during both fixed and flexible exchange rate regimes.

Cointégration, correction d'erreurs et parité du pouvoir d'achat entre le Canada et les Etats-Unis. Le concept de cointégration et la représentation qui y est associée d'un processus dynamique qui corrige ses erreurs (voir Engle & Granger 1987) sont utilisés pour étudier la relation de parité du pouvoir d'achat entre le Canada et les Etats-Unis. Les résultats supportent la parité du pouvoir d'achat en tant que relation à long terme entre prix canadiens, prix américains et taux de change entre les devises canadienne et américaine. La relation est maintenue même si différents mécanismes dynamiques ont opéré tant au cours de la période des changes fixes qu'au cours de la période des changes flexibles.

I. INTRODUCTION

Purchasing power parity, (PPP), is one of the foundations of price and exchange rate behaviour in an open economy. Surveys of PPP are found in Officer (1976), Katseli-Papaefstratiou (1979), and Levich (1985). Although PPP is firmly embedded in virtually all discussions of exchange rate theory and policy, the validity of PPP remains open to question. This study utilizes the error-correction mechanism and the concept of co-integration associated with Engle and Granger (1987) to explore the PPP relationship between Canada and the United States.

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A major finding of this study is substantial evidence in favour of a PPP relationship between Canadian and American prices and the Canadian dollar – American dollar exchange rate, particularly over the 1950–86 period. There is evidence of co-integration among the appropriate vectors of time series. The error-correction terms (the deviations from the PPP relationship) are consistently significant in explaining changes in the exchange rate in periods of flexible exchange rates and are usually significant in explaining changes in domestic prices in periods of either flexible or fixed exchange rates.

The second major finding of this study is that different error-correction models of exchange rate change and price change must be estimated from subperiods of the data that correspond to different exchange rate regimes. If exchange rates are fixed, adjustment towards PPP takes place only through the adjustment of the domestic inflation rate. If exchange rates are flexible, then both the domestic inflation rate and the level of the exchange rate can adjust in maintenance of PPP. The choice of nominal exchange rate regime has a strong effect on the mechanism through which PPP is maintained.

The paper proceeds as follows. The relationship of the present study to the existing literature is considered in section II. Section III outlines the implementation of the tests for co-integration and the estimation of the error-correction models including the PPP relationship. The results are presented and discussed in Section IV.

II. RELATED LITERATURE

The economic framework of Engle and Granger (1987) has two advantages over previous approaches to the study of PPP: (1) The concept of co-integration deals with the analysis of long-run equilibrium relationships between non-stationary time series. Prices and exchange rates are non-stationary time series; PPP is their long-run relationship. (2) In estimation of an error-correction model of price or exchange rate change, a flexible short-run dynamic process is constrained to achieve long-run equilibrium. Given these two important advantages, other researchers have considered the validity of PPP in the framework of co-integrated variables.

Corbae and Ouliaris (1988), using a frequency-domain approach, use post-1973 data from six countries in a test of PPP. They find support for PPP only in the Canadian-U.S. case. Mark (1987) uses the Engle-Granger time-domain approach to test PPP after 1973 between the United States and five countries (including Canada). He is unable to find support for PPP in the Canadian-American case. Baillie and Selover (1987) and Taylor (1988), also with post-1973 data, cannot find support for PPP in the Canadian-American case. Enders (1988) considers PPP between the United States and three countries. He finds mixed evidence in favour of PPP in the Canadian-American case.

The present paper differs from other studies of PPP in the co-integration framework in two important ways. First, a long, in absolute time, series of observations is used; thirty-six years of quarterly data and 100 years of annual data. There is some evidence that the length of sample is important in considering the properties of the real exchange rate and the maintenance of PPP. Frankel (1986) finds support for the idea that PPP between the United States and the United Kingdom increases as the sample length increases. Hendry (1986) argues that the concept of co-integration and the search for long-run economic relationships require not just large numbers of observations but data over a long period of time. All previous studies of PPP in the co-integration framework, except Enders (1988), consider only the post-1973 floating exchange rate period. However, Enders chooses to analyse only subsamples (corresponding approximately to periods of fixed and flexible exchange rates) drawn from the post-1960 period.

Second, this study estimates error-correction mechanisms for exchange rate change and domestic price change that vary by choice of exchange rate regime. The concept and measurement of PPP is not restricted to a specific exchange rate regime; the mechanism for the maintenance of PPP is specific to each exchange rate regime. When nominal exchange rates are flexible, both the nominal exchange rate and the domestic inflation rate can respond to deviations from PPP. When nominal exchange rates are fixed, only the domestic inflation rate can adjust to correct deviations from PPP.

Edison (1987) estimates an error-correction model of the U.S.-U.K. nominal exchange rate using annual data from 1890 to 1986. Part of the present study is the estimation of an error-correction model of the U.S.-Canadian nominal exchange rate using annual data from 1914 to 1986. Both the present study and Edison find some evidence in favour of PPP. However, Edison does not estimate error-correction models that vary by exchange rate regime; or pre-test for co-integration of the relevant variables; or estimate the associated error-correction model of domestic inflation.

III. COINTEGRATION, ERROR-CORRECTION, AND PURCHASING POWER PARITY

The PPP relationship is

$$P = KEP^* \tag{1}$$

where the variables are

P = domestic currency (Canadian dollar) price index
P^* = foreign currency (American dollar) price index
E = the exchange rate, the domestic currency (Canadian dollar) price of a unit of foreign (American dollar) currency
K = a constant.

The operational definition of PPP, 'relative PPP,' is that (1) holds in the long run for a constant value of K.[1] The application of the concept of co-integration to the PPP relationship is considered below.

1 K equals unity if there is perfect arbitrage between all goods in both countries and the bundles that define the national price indexes are composed of identical goods. This is unlikely to be the case.

Co-integration

Engle and Granger (1987) define a co-integrated vector time series X_t, denoted CI(d, b) if

1. each element of X_t is integrated of order d
2. there exist up to r linear combinations of X_t such that each element of a vector times series Z_t is integrated of order $(d - b)$ where Z_t is defined by

$$Z_{t\ rx1} = \alpha'_{rxN} X_{t\ Nx1}. \tag{2}$$

Co-integrated vectors occur frequently in macro-economic theory and there is a burgeoning literature in their applications.[2]

For the study of PPP the vector time series X_t has two elements and may be written as

$$\begin{bmatrix} \ln P_t \\ \ln (E_t P_t^*) \end{bmatrix} \tag{3}$$

or

$$\begin{bmatrix} \ln E_t \\ \ln (P_t / P_t^*) \end{bmatrix}. \tag{4}$$

Previous studies have found that the logarithms of P_t, P_t^* and E_t (when nominal exchange rates are flexible) are integrated of order 1.[3] The logarithms of P_t, P_t^*, E_t, $E_t P_t^*$ and P_t/P_t^* are in fact series with single unit roots over the sample in this study.[4]

The normalized vector α is defined as

$$\alpha = \begin{bmatrix} 1 \\ -\alpha_1 \end{bmatrix}. \tag{5}$$

Co-integration requires that α when multiplied by either (3) or (4) yields a variable

$$Z_t = \alpha' X_t, \tag{6}$$

2 Some examples are Engle and Granger (1987) and Campbell (1987) who study the consumption-income relationship; Stock and Watson (1986) and Campbell and Shiller (1987) who study the term structure of interest rates; and Hall (1986) and Jenkinson (1986) who study the behaviour of real wages.

3 Wasserfallen (1986) and Nelson and Plosser (1982) cannot reject the hypothesis that many macro-economic time series, including price indexes, have unit roots. Meese and Singleton (1982) show that nominal exchange rates contain a unit root over the floating exchange rate period. The other studies of PPP and co-integration as cited above also find that the variables in X_t (as defined in (4)) have unit roots.

4 In general the sum or difference of two series that individually contain a unit root also contains a unit root. Co-integration is of interest precisely because the linear combination of integrated variables is stationary. The standard tests for the presence of a unit root, a unit root with drift, or a unit root with trend are found in Fuller (1976) and Dickey and Fuller (1981).

where Z_t is stationary (integrated of order $d - b = 0$). A stationary variable has finite variance, a constant mean, and a tendency to return to that mean in a finite length of time. If Z_t is stationary, then PPP is a meaningful concept. The difference between Z_t and its mean is interpreted as the percentage deviation of the domestic prive level or the exchange rate from the PPP equilibrium level. The null hypothesis is that the bivariate time series X_t, (3) or (4), is not co-integrated. If this null hypothesis is rejected, then the PPP relationship receives empirical support.[5]

Error-correction models

Engle and Granger (1987) prove that if X_t is co-integrated, then the change in X_t has an error-correction representation. This representation, also suggested by Davidson et al. (1978), allows for much flexibility in short-run dynamics while the model is constrained to return to long-run equilibrium.

The general error-correction representation is

$$A^*(B)(1 - B)X_t = -\gamma Z_{t-1} + d(B)\epsilon_t, \tag{7}$$

where B is the backshift operator. Granger's Representation Theorem (1987) includes the following results:

1. $A^*(0) = I$.
2. $(1 - B)X_t$ is a stationary stochastic process.
3. There exists some lag length in $A^*(B)$ where $d(B)$ is unity.
4. ϵ_t is multivariate white noise.
5. Z_{t-1} is defined as deviations from the cointegrating regression.

Expression (7) is the error-correction mechanism for any cointegrated vector time series X_t. The particular set of error-correction models estimated and their parameter values depend on whether the nominal exchange rate regime is fixed or flexible.

The domestic price level can change in a fixed or flexible exchange rate regime. The error-correction mechanism for the change in the domestic price level, the inflation rate, using (7) and (3) is

$$\Delta \ln P_t = \sum_{i=1}^{i=n_0} \Delta \ln P_{t-i} + \sum_{i=1}^{i=n_1} \Delta \ln (E_{t-i}P^*_{t-i}) - \gamma_1(\ln P_{t-1} - \alpha_1 \ln (E_{t-1}P^*_{t-1}) - \alpha_0) + \epsilon_t. \tag{8}$$

5 There is also a substantial literature that tests the null hypothesis that the logarithm of the real exchange rate contains a unit root (is non-stationary). The evidence is mixed. See Adler and Lehman (1983), Roll (1973), Frenkel (1981), Mishkin (1984), Cumby and Obstfelt (1984), Frankel (1986), and Huizinga (1987). Footnote 10 contains some results of unit root tests on the data in this study. Testing for co-integration of the vector time series (3) or (4) is equivalent to testing the null hypothesis that the logarithm of the real exchange rate is stationary. Since the residuals from the co-integrating regression are important inputs into the error-correction model this study tests for co-integration.

n_0 and n_1 are sufficient to reduce the appropriate element of the error term to white noise. The term in parentheses following γ_1 is the lagged residual from the co-integrating regression

$$\ln P_t = \alpha_0 + \alpha_1 \ln (E_t P_t^*) + e_t. \tag{9}$$

The lagged residual from this regression, e_{t-1}, is the error-correction term, the estimated lagged deviation from PPP. If γ_1 is positive and significantly different from zero, then the domestic price level tends to move to restore the long-run PPP relationship. Engle and Granger (1987) and Stock (1987) show that (9) yields consistent estimates of α_0 and α_1.[6] Engle and Granger (1987) show the two-step procedure to estimate (8) and (9) is consistent and asymptotically efficient.[7]

The domestic price level could and does adjust toward its PPP level whether exchange rates are fixed or flexible. It is expected that the parameters of the error-correction model of inflation would be different under different exchange rate regimes. The more the authorities allow the nominal exchange rate to change, the less the required adjustment of domestic prices to maintain PPP. Thus equation (8) is estimated separately over time periods that correspond to fixed and flexible exchange rate regimes.

If the exchange rate is flexible the cointegrating regression is written as

$$\ln E_t = \alpha_0' + \alpha_1' \ln (P_t / P_t^*) + e_t'. \tag{10}$$

The error-correction model of the change in the exchange rate is

$$\Delta \ln E_t = \sum_{i=1}^{i=n_0} \Delta \ln E_{t-i} + \sum_{i=1}^{i=n_1} \Delta \ln (P_{t-i}/P_{t-i}^*) - \gamma_1(\ln E_{t-1} - \alpha_0' - \alpha_1' \ln (P_{t-1}/P_{t-1}^*)) + \epsilon_t. \tag{11}$$

The term following γ_1 is the error-correction term to force the adjustment of the nominal exchange rate towards its PPP value. Equation (11) can be estimated only from periods of data when nominal exchange rates were allowed to move.

If PPP holds and $\alpha_1 = \alpha_1' = 1$, the error-correction terms in (8) and (11) are different normalizations on the same equilibrium relationship. In practice, the residuals from regressions (9) and (10) are nearly equal in magnitude and opposite in sign. Both error-correction models, (8) and (11), are estimated with the residuals from

6 Stock (1987) shows this property holds even if both variables are endogenous. Bannerjee et al. (1986) show the simultaneous-equations bias in the co-integrating regression is small as long as the R^2 in the regression is high.

7 Stock (1987) compares, using Monte Carlo analysis, the one-step non-linear squares estimate of (8) with the two-step estimates using (8) and (9). Both estimates are consistent and produce appropriate standard errors. Stock's results and those of Bannerjee et al. (1986) suggest the one-step estimate may be slightly better. The one-step estimator is not available in this study because the error-correction mechanisms, although not the estimation of deviations from PPP, differ by exchange rate regime.

(9). This allows the co-integrating regression to be estimated from the longest possible time series, as suggested by Hendry (1986), and allows the error-correction mechanism to vary across different nominal exchange rate regimes. Use of the residuals from (9) as error-correction terms in both the error-correction model of prices (8) and exchange rates (11) means γ_1, the coefficient on the error-correction term, should have opposite signs in (8) and (11). If the residual in (9) is positive, Canadian goods are expensive relative to their foreign counterparts. If the residual in (9) is positive, Canadian prices tend to fall in (8) or the exchange rate (Canadian cents per U.S. dollar) in (11) tends to depreciate.

IV. RESULTS

This study produces substantial evidence in favour of PPP between Canada and the United States. Tests for co-integration reveal a long-run relationship between national price levels expressed in the same currency. In the associated error-correction model of the change in the nominal exchange rate when exchange rates are adjustable, the deviation from PPP, the error-correction term, is consistently significant and of the correct sign. Whether nominal exchange rates are fixed or flexible, the error-correction term usually plays a role in the determination of the rate of change of Canadian prices. The error-correction mechanisms, as anticipated, do vary by exchange rate regime. The structure of the data set and its division into periods of fixed and flexible exchange rates is considered below.

Structure of data

Two data sets are analysed, an annual data set (1870–1986) and a quarterly data set (1950.3–1986.4).[8] The annual data is divided into three periods: a brief floating exchange rate period 1870–8 (the greenback era), a longer fixed exchange rate period 1879–1913 (the gold standard), and a period of adjustable nominal exchange rates 1914–86. The 1914–86 time period does include subperiods where nominal exchange rates were fixed for up to a decade.

The quarterly data 1950.3–1986.4 are also divided into three periods. Canada began its first post-war flexible exchange rate regime on 30 September 1950. The error-correction models of changes in the exchange rate or the price level are estimated starting in 1952.1, that is, after the complete removal of wartime foreign exchange controls on 14 December 1951.[9] Although the Canadian dollar was not formally fixed until 2 May 1962, the budget speech of 20 December 1960 included a clear announcement that any further appreciation of the Canadian dollar would be resisted and that a substantial depreciation of the Canadian dollar was the longer-term goal of the government. In the present study the end of flexible

8 Details concerning sources are found in the data appendix.

9 A description of the purpose and mechanism of foreign exchange control is found in Rasminsky (1941) or Gibbons (1953). It is clear from the *Annual Reports*, Foreign Exchange Control Board (1947 through 1951) that foreign exchange controls and other restrictions on imports were almost completely relaxed by the beginning of the flexible exchange rate regime on 30 September 1950.

exchange rates is set at 1960.4.[10] The period of fixed exchange rates is then set from 1961.1 to 1970.1. The recent period of flexible exchange rates is from 1970.2 to 1986.4.[11] Although the error-correction models of inflation or exchange rate change are estimated using the subperiods corresponding to the different exchange rate regimes, tests for co-integration are carried out for the longest possible time periods spanning the different exchange rate regimes.

Tests for co-integration

Table 1 presents the estimates of the co-integrating regressions (9) and (10) for the annual data, two subperiods of the annual data and the quarterly data.

Engle and Granger (1987) outline and provide critical values, included in table 1, for three test statistics that serve as a 'rough guide' in testing the null hypothesis that a bivariate vector times series is co-integrated. The intuition for these statistics is as follows. If PPP holds the estimated deviations from PPP, the residual e_t from the co-integrating regression (9) or (10), cannot be non-stationary.[12] If the residual were non-stationary the real exchange rate would drift away from its PPP value. A Durbin-Watson (DW) statistic that is close to zero indicates the hypothesis that deviations from PPP are non-stationary cannot be rejected. A second test statistic is based on the t-statistic (DF) of the coefficient p in the regression

$$\Delta e_t = p e_{t-1}, \tag{12}$$

where e_t is the residual from the co-integrating regression (9) or (10). The estimate of p must be large enough to reject the hypothesis that the residuals from the PPP regression are non-stationary. A similar t-statistic (the ADF statistic) is constructed from the estimate of p in

$$\Delta e_t = p e_{t-1} + \sum_{i=1}^{s} s_i \Delta e_{t-i}. \tag{13}$$

The use of the ADF statistic is recommended over the DF statistic if the coefficients s_i are non-zero or there is a possibility of seasonal dynamics. In table 1 the appropriate statistic is presented for each co-integrating regression.

There is some evidence that the annual times series are co-integrated. Equation (9) is estimated using the full data period, 1870–1986, the gold standard period,

10 Plumptre (1970, 3) states: 'The period of float came to an end *de facto* in 1961 when the Canadian government took a position in regard to the (foreign exchange) rate and *de jure* in May 1962.' Wonnacott (1965), Shepherd (1973), and, of course, Plumptre (1977) arrive at the same conclusion.

11 The substantive results for the error-correction models in tables 3 and 4 are not changed if 1950.3–1962.1 is used as the early period of flexible rates and 1962.2–1970.1 is used as the period of fixed exchange rates. I am grateful to an anonymous referee for pointing out the necessity of being careful in dating the transition from flexible to fixed exchange rates between 1960 and 1962.

12 Pippenger (1986) employs a similar methodology in analysing the residuals from PPP using spectral analysis.

TABLE 1
Co-integrating regressions

Equation	Period	Estimate[a]	Statistics[b]
1.1	1870–86	$\ln P_t = -4.21 + 0.962 \ln (E_t P^*_t)$	$R^2 = 0.994$ DW = 0.432 DF = −3.79
1.2	1879–1913	$\ln P_t = -3.83 + 0.913 \ln (E_t P^*_t)$	$R^2 = 0.802$ DW = 0.693 DF = −2.60
1.3	1914–86	$\ln P_t = -4.42 + 0.985 \ln (E_t P^*_t)$	$R^2 = 0.992$ DW = 0.430 DF = −2.99
1.4	1914–86	$\ln E_t = 4.58 + 0.674 \ln (P_t/P^*_t)$	$R^2 = 0.430$ DW = 0.366 ADF(2) = −2.36
1.5	1950.3–86.4	$\ln P_t = -4.35 + 0.974 \ln (E_t P^*_t)$	$R^2 = 0.988$ DW = 0.263 ADF(4) = −4.15
1.6	1950.3–86.4	$\ln E_t = -4.59 + 0.942 \ln (P_t/P^*_t)$	$R^2 = 0.635$ DW = 0.232 ADF(4) = −3.77

a No standard errors are reported in the co-integrating regressions. Computed standard errors in regressions involving non-stationary variables are understated. Regressions (1.2), (1.3), and (1.5) are used in generation of the deviations from PPP, the error-correction terms.

b Critical values (1, 5, and 10 per cent) to reject the null hypothesis of no co-integration in a bivariate time series are provided in Granger and Engle (1987) and reproduced below. Rejection of the null hypothesis indicates support of the PPP proposition.

Statistic	*Model A*			*Model B*		
	1%	5%	10%	1%	5%	10%
DW	0.511	0.386	0.322	0.455	0.282	0.204
DF	4.07	3.37	3.03	3.90	3.05	2.71
ADF(S)	3.77	3.17	2.84	3.73	3.17	2.91

Model B allows for more extensive dynamics, including seasonal effects. The three test statistics are discussed briefly in the text and extensively in Engle and Granger (1987). S is the number of lags in regression ( ) for the ADF statistic.

1879–1913, and the period of adjustable exchange rates, 1914–1986. In each case the point estimate of α is near unity, as predicted by PPP. The DW statistic rejects the null hypothesis of no co-integration in all three cases at 5 per cent or higher. The DF statistic rejects the null hypothesis of no co-integration at 5 per cent using the full sample and at nearly 10 per cent using the 1914–86 subsample. Equation (10) is estimated (see equation (1.4)) using the 1914–86 period of adjustable exchange rates. Only the DW statistic provides any suggestion of co-integration.

Evidence for co-integration is substantially stronger in the post-1950 quarterly data. The estimates of both α and α' from equations (9) and (10) (see equations (1.5) and (1.6)) are close to unity, as predicted by PPP. Both ADF statistics reject the

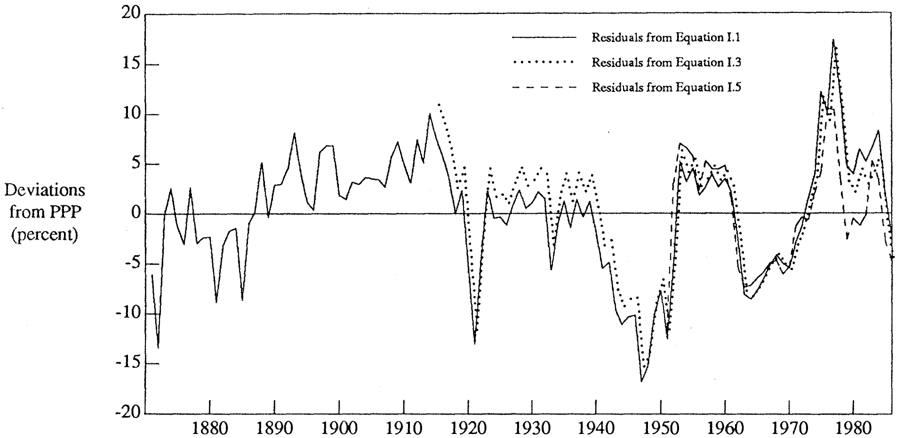

FIGURE 1 Deviations from purchasing power parity, 1870–1986 (SOURCE: Residuals from co-integrating regressions in table 1

null hypothesis of no co-integration at 1 per cent, both Durbin-Watson statistics reject the null at 10 per cent.[13]

Figure 1 plots the residuals from equations (1.1), (1.3), and (1.5). All three co-integrating regressions generate a similar a pattern of residuals. The lagged values of these residuals are used as the error-correction terms.

Error-correction models

Annual data

Table 2 presents estimates of the error-correction models using annual data. During the gold standard the nominal exchange rate is fixed. Only prices are able to adjust to maintain PPP. Equation (2.1) models the adjustment in domestic inflation over the 1880–1913 period. The error-correction term is of the correct sign, although it is not statistically significant. This insignificant error-correction coefficient is consistent with the weak rejection of the null hypothesis of no co-integration in equation (1.2). A strong mechanism for the maintenance of PPP does not emerge in the gold standard period.

It is necessary to ensure the residuals in equation (2.1) and all other error-

13 Tests following Fuller (1976), Dickey and Fuller (1981), or Hasza and Fuller (1982), as appropriate, were conducted on the logarithm of the real exchange rate. The null hypothesis that the logarithm of the real exchange rate contains a unit root cannot be rejected for the annual samples from 1879–1986 and 1879–1913. The null hypothesis is rejected ($\hat{\tau}_\mu = -2.97$) for the 1914–86 subperiod. The null hypothesis is also rejected for the full sample of quarterly data (1950.3–1986.4) ($\hat{\tau} = -4.023$) and is rejected only at a 0.10 level of significance ($\hat{\tau}_\mu = -2.70$) for the quarterly subsample from 1973–86. It is noteworthy that most studies that reject PPP through the inability to reject the null hypothesis of a unit root in the logarithm of the real exchange rate restrict themselves to the post-1973 period. Critical values of $\hat{\tau}_\mu$ are found in Fuller (1976). The results of tests for the unit root correspond exactly to the results of tests for co-integration in table 1.

TABLE 2
Error-correction models, annual data

Equation	Period	Estimate[a,b]	CI regression[c]
2.1	1880–1913	$\Delta \ln P_t = 0.184\, \Delta \ln P_{t-1} - 0.185\, \text{EC}_t$ (0.192) (0.184) $R^2 = -0.052$ $Q + (3) = 0.007$	1.2
2.2	1915–86	$\Delta \ln E_t = 0.328\, \Delta \ln E_{t-1} - 0.220\, \Delta \ln E_{t-2}$ (0.110) (0.111) $+0.181\, \text{EC}_t$ (0.059) $R^2 = 0.203$ $Q + (3) = 0.010$	1.2
2.3	1915–86	$\Delta \ln P_t = 0.734\, \Delta \ln P_{t-1} - 0.187\, \Delta \ln P_{t-2}$ (0.116) (0.143) $+0.251\, \Delta \ln P_{t-3} + 0.054\, \text{EC}_t$ (0.116) (0.080) $R^2 = 0.361$ $Q + (3) = 0.200$	1.3

a Standard errors in parentheses
b The $Q + (p)$ statistic is distributed $F(p, T - p - k)$ on the null hypothesis of p zero autocorrelations in the residuals from a regression including lagged dependent variables. T is the number of observations and k the number of regressors.
c The error-correction term EC_t is the lagged residual from the cointegrating (CI) regression in table 1. A significant coefficient on this term indicates that the deviation from PPP affects the path of the nominal exchange rate or the Canadian inflation rate.

correction models are serially uncorrelated. A Lagrange multiplier test statistic $Q+(p)$ (Harvey 1981) is used to test the null hypothesis that the first p autocorrelations are zero. The $Q+(p)$ statistic is recommended when the regression involves, as all error-correction models do, a lagged dependent variable. This test statistic is reported in each case.

Over the 1914–86 period there were a number of changes in the nominal exchange rate. An error-correction model of exchange rate change, equation (2.2), contains an error-correction term which is correctly signed and statistically significant. This is evidence to add to the somewhat mixed evidence in favour of co-integration from equations (1.1), (1.3), and (1.4). Equation (2.2) suggests that a 10 per cent deviation from PPP is followed, on average, by a 2 per cent annual change in the exchange rate. The model can also be interpreted to suggest that the Canadian monetary authorities took deviations from PPP into account in intervention to affect or fix a nominal exchange rate.

Equation (2.3) is the error-correction representation of the rate of change in the Canadian price level over the 1914–86 period. The error-correction term is incorrectly signed, small in absolute magnitude, and statistically insignificant.

The combination of (2.2) and (2.3) leads to an interesting and useful interpretation concerning the mechanisms through which PPP is maintained. Lags of foreign inflation and domestic inflation are not significant when added to equation (2.2), the error-correction model of the change in the exchange rate. Such variables could, but need not, enter into this model (see equation (7)). The importance of domestic or foreign inflation for exchange rate change is completely captured by the error-correction term. Similarly lagged exchange rate change and lagged foreign inflation do not enter equation (2.3), the error-correction model of domestic inflation. If nominal exchange rates are truly adjustable, the domestic price process is independent of the foreign price process.[14]

Quarterly data

The estimates of quarterly error-correction models appear in tables 3 and 4. They provide further insight into the fact that PPP can be maintained in different ways over different exchange rate regimes. Equations (3.1) and (3.2) model nominal exchange rate change in the early (1950s) and later (after 1970) flexible exchange rate regimes. The coefficient on the error-correction term is significant in both periods but twice as large in the second period of floating rates. A stronger response of the exchange rate to deviations from PPP is an important feature of the second period of flexible exchange rates.

Further support for the importance of changes in regime is found when error-correction models of inflation are estimated separately over the two flexible exchange rate periods. Two error-correction models of inflation are estimated for each period of flexible exchange rates. Equations (3.5) and (3.6) allow for the possibility of seasonality in inflation. Equations (3.3) and (3.4) do not explicitly allow for seasonality, although only the fourth lag of inflation is significant in either equation. The equations reveal that the mechanism for the maintenance of PPP through variations in the domestic inflation rate did vary over the two flexible exchange rate regimes. In the 1950s float, where the adjustment in the nominal exchange rate is weaker, the role of error-correction in the determination of domestic inflation is stronger. The coefficient on the error-correction term in equation (3.3) is twice as large as in equation (3.4). In the latter equation, the coefficient on the error-correction term is not statistically significant. The coefficient pattern is similar in comparing equations (3.5) and (3.6). In equation (3.6), the coefficient on the error-correction term is statistically significant but only one-half the magnitude of the equivalent coefficient in equation (3.5). In the post-1970 flexible exchange rate period, the nominal exchange rate was allowed more freedom to move and the role of error-correction in the determination of domestic inflation is much smaller. This corresponds closely to the textbook model of a pure flexible exchange rate regime.

If the nominal exchange rate is fixed, only the domestic inflation rate is able to adjust to maintain the PPP relationship. Error-correction models of inflation estimated using data from the fixed exchange rate period are found in table 4. Intervention to reduce and then fix the value of the Canadian dollar between 1960 and 1962 involved, according to figure 1, a significant depreciation of both the real

14 Engle and Granger (1987) note the absence of a significant error-correction term in one of the error-correction equations corresponds to weak exogeneity of that variable. Thus if exchange rates are truly flexible, domestic inflation is weakly exogenous. The long annual data period includes a substantial depreciation of the Canadian dollar.

TABLE 3
Error-correction models, quarterly data, flexible exchange rates[a]

Equation	Period	Estimate[b,c]	CI regression[d]
3.1	1952.1–60.4	$\Delta \ln E_t = 0.438\, \Delta \ln E_{t-1} + 0.063\, \text{EC}_t$ $(0.147)\quad (0.030)$ $R^2 = 0.237 \quad Q + (4) = 0.288$	1.5
3.2	1970.2–86.4	$\Delta \ln E_t = 0.353\, \Delta \ln E_{t-1} + 0.113\, \text{EC}_t$ $(0.104)\quad (0.031)$ $R^2 = 0.257 \quad Q + (4) = 1.40$	1.5
3.3	1952.1.4–60.4	$\Delta \ln P_t = 0.698\, \Delta \ln P_{t-4} - 0.128\, \text{EC}_t$ $(0.104)\quad (0.069)$ $R^2 = 0.586 \quad Q + (4) = 0.688$	1.5
3.4	1970.2–86.4	$\Delta \ln P_t = 0.887\, \Delta \ln P_{t-4} - 0.039\, \text{EC}_t$ $(0.058)\quad (0.035)$ $R^2 = 0.650 \quad Q + (4) = 0.750$	1.5
3.5	1952.1–60.4	$\Delta^4 \ln P_t = 0.542 \Delta^4 \ln P_{t-1} + 0.251 \Delta^4 \ln P_{t-2}$ $(0.157)\quad (0.153)$ $-0.136\, \text{EC}_t$ (0.061) $R^2 = 0.583 \quad Q + (4) = 1.96$	1.5
3.6	1970.2–86.4	$\Delta^4 \ln P_t = 0.822 \Delta^4 \ln P_{t-1} + 0.176 \Delta^4 \ln P_{t-2}$ $(0.123)\quad (0.125)$ $-0.076\, \text{EC}_t$ (0.037) $R^2 = 0.830 \quad Q + (4) = 0.537$	1.5

a The flexible exchange rate period in the 1950s is dated from the removal of foreign exchange controls on 14 December 1951 to the beginning of active intervention in foreign exchange markets as announced on 20 December 1960. See text for further discussion.
b Standard errors in parentheses
c The $Q + (p)$ statistic is distributed $F(p, T - p - k)$ on the null hypothesis of p zero autocorrelations in the residuals from a regression including lagged dependent variable. T is the number of observations and k the number of regressors.
d The error-correction term EC_t is the lagged residual (fourth lag of the residual in equations (3.5) and (3.6)) from the co-integrating regression in table 1. A significant coefficient on this term indicates that the deviation from PPP affects the path of the nominal exchange rate or the Canadian inflation rate.

and nominal exchange rate. The error-correction term that responds to that undervaluation is large and strongly significant in both equations in table 4. Canadian inflation during the 1960s was accelerated by the return towards the PPP relationship. It is also noteworthy that in equation (4.2), the seasonally adjusted model of Canadian inflation, lagged American inflation has a statistically significant impact, independent of the error-correction mechanism, on Canadian inflation. No such effects could be found in the error-correction models of domestic price change or exchange rate change when exchange rates were flexible. The direct influence of foreign inflation on domestic inflation is part of the textbook model of a fixed exchange rate regime.

TABLE 4
Error-correction models, quarterly data, fixed exchange rates[a]

Equation	Period	Estimate[b,c]	CI regression[d]
4.1	1961.1–70.1	$\Delta \ln P_t = 0.576\,\Delta \ln P_{t-4} - 0.065\,\text{EC}_t$ (0.131) (0.018) $R^2 = 0.354$ $Q + (4) = 2.14$	1.5
4.2	1961.1–70.1	$\Delta^4 \ln P_t = 0.376\Delta^4 \ln P_{t-1} + 0.324\Delta^4 \ln P_{t-2}$ (0.170) (0.159) $+ 0.182\Delta^4 \ln P^*_{t-2} - 0.088\,\text{EC}_t$ (0.084) (0.031) $R^2 = 0.873$ $Q + (4) = 1.36$	1.5

a The period of fixed exchange rates is dated from 20 December 1960, when the authorities announced active intervention to reduce the value of the Canadian dollar. Exchange rates were officially fixed on 2 May 1962. See text for further discussion.
b Standard errors in parentheses
c The $Q + (p)$ statistic is distributed $F(p, T - p - k)$ on the null hypothesis of p zero autocorrelations in the residuals from a regression including lagged dependent variable. T is the number of observations and k the number of regressors.
d The error-correction term EC_t is the lagged residual (fourth lag of the residual in equation 4.2) from the co-integrating regression in table 1. A significant coefficient on this term indicates that the deviation from PPP affects the path of the Canadian inflation rate.

IV. CONCLUSIONS

The more extensive dynamic framework adopted in this study uncovers significant new evidence in favour of PPP as the long-run relationship between Canadian prices, American prices, and the Canadian dollar / American dollar exchange rate. The relevant time series are co-integrated after 1950, and there is some evidence in favour of co-integration over the post-1914 period. Error-correction terms play a significant role in modelling both the change in the nominal exchange rate and, to a slightly smaller extent, the change in the price level.

The results also yield useful insights into the mechanism for maintenance of PPP. This mechanism clearly depends on the choice of exchange rate regime. Over the entire 1914–86 period, and to some extent after 1970, the results of this study suggest that a fully adjustable nominal exchange rate allows Canadian inflation to be independent of the American inflation. After 1950 three nominal exchange rate regimes were implemented. During the period of fixed nominal exchange rates during the 1960s PPP is maintained through adjustment of Canadian prices toward their PPP level. When the exchange rate was fixed, Canadian inflation responded directly to American inflation. The two post-1950 periods of flexible exchange rates were different. The period of exchange rate flexibility after 1970 corresponded more closely to the textbook model of flexible exchange rates. The flexible nominal exchange rate responded strongly to deviations from PPP after 1970. There was only a small response of Canadian inflation to deviations from PPP in the 1970s rather than the larger response in the 1950s. In the 1950s the nominal exchange rate, though flexible, moved less in response to deviations from PPP than in the 1970s. The implementation of exchange rate policy and the choice of exchange rate regime have a strong effect on the mechanism through which PPP is maintained and thus a strong effect on the domestic inflation process.

APPENDIX: DATA SOURCES

Annual data

GNP Deflator – United States

1870–1983 Nathan S. Balke and Robert J. Gordon (1986) 'Historical data.' In Robert J. Gordon, ed., *The American Business Cycle: Continuity and Change* (Chicago: University of Chicago Press)

1983–86 Bureau of Economic Analysis, U.S. Department of Commerce (February 1987) *Survey of Current Business*

GNP Deflator – Canada

1870–1926 M.C. Urquhart (1986) 'New estimates of gross national product, Canada, 1870–1926: some implications for Canadian developments.' In Stanley L. Engerman and Robert E. Gallman, eds, *Long-Term Factors in American Economic Growth* (Chicago: University of Chicago Press)

1926–86 CANSIM Variable D40672.

Exchange Rate – Canadian cents per U.S. dollar

1870–78 James K. Kindahl (1961) 'Economic factors in specie resumption: the United States 1865–79.' *Journal of Political Economy* 69, 30–48. This source provides the greenback price of a gold U.S. dollar and hence the exchange rate per Canadian dollar.

1879–1913 The U.S. and Canadian dollar are defined as and fully convertible into the same amount of gold. The exchange rate is unity.

1914–45 Column J562 (1983) 'Average daily noon exchange rate.' In F.H. Leacy, ed. *Historical Statistics of Canada*, Second Edition (Ottawa: Statistics Canada)

1946–86 The annual average of CANSIM Variable B40001, a monthly exchange rate series constructed from an average of daily observations.

Quarterly data

GNP Deflator – United States

1947.1–1950.4 Federal Reserve Bank of St Louis

1951.1–1984.4 Bureau of Economic Analysis, U.S. Department of Commerce (February 1986) *A Supplement to the Survey of Current Business*

1985.1–1986.4 Bureau of Economic Analysis, U.S. Department of Commerce (February 1987) *Survey of Current Business*

GNP Deflator – Canada

1947.4–1986.4 CANSIM Variable D40012 (current dollar GNP) divided by CANSIM Variable D40561 (constant dollar GNP)

Exchange Rate – Canadian cents per U.S. dollar
1946.1–1986.4 Quarterly Average of CANSIM Variable B40001, a monthly average of daily observations

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