FORECASTING CANADIAN EXCHANGE RATES: AN ECONOMETRIC SURVEY

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ABSTRACT

This paper evaluates various exchange rate models, considers their predictive performance effectiveness after applying parametric and nonparametric techniques to them, and chooses the exchange rate forecasting predictor with the smallest root mean square forecast error (RMSE). The autoregressive model in Equation (34) shows the most consistent evidence of being a better model, although none of the empirical evidence here gives us a wholly satisfactory forecast. The models' error correction versions will be fit so that reasonable long-run elasticities can be imposed on each model's fundamental variables.

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1. INTRODUCTION

The greatest number of economic time series lack an invariant mean, as they alternate relatively stable periods with more volatile ones. A brief look at foreign currency exchange rates, among other time-series data, suggests that they are heteroscedastic because of this missing constant mean and variance, as opposed to being homoscedastic because of a stochastic variable's existence with a corresponding constant variance. For any such volatile series, the unconditional variance could be constant even though it may also be unusually large. Some variables' trends may contain stochastic or deterministic elements, with the analysis (i.e., estimation and forecasting) of such ingredients corresponding to these two types of trend characteristics, thus heavily influencing the time series estimates.

One may illustrate the behavior of different exchange rates by graphing them, documenting their variations across time, and looking for confirmation of first impressions through a series of tests. For example, one notices that these series are not stationary, in that the sample means do not appear to be constant while simultaneously having a strong appearance of heteroscedasticity. This absence of an exact trend makes it difficult to prove the assertion that these series possess a time-invariant mean; for example, the American vs. Canadian dollar exchange rate does not show a tendency to either increase or decrease, with the U.S. dollar apparently going through long periods of both appreciation and depreciation without reversion to a long-run average. This type of "random walk" behavior is quite typical of nonstationary time series.

Any shock to such a series displays a high degree of persistence. The U.S. dollar/British pound exchange rate, for instance, experienced a tremendous upward surge in 1980, remained at this level into 1984, and only returned somewhere near its level of 1980 at the end of the decade. The volatility of these series is not constant and some exchange rate series do have a partial correlation with other series, with such series termed "conditionally heteroscedastic" if the unconditional or long-run variance is constant overall but interspersed with localized periods of somewhat higher variance. For example, large shocks in the U.S. appear at about the same time in Canada and Great Britain, although these co-movements' existence can be all but predicted because of the underlying forces affecting the economies of the U.S. and all other countries.

The disturbance term's variance is assumed to be constant in conventional econometric models, although our series alternates periods of tremendous volatility with tranquil spells. Therefore, our assumption of a constant variance in such cases cannot be correct. As an investor holding one currency, though, one may wish to forecast both the exchange rate and its conditional variance over the life of the investment in such an asset. The unconditional variance and its long-run forecast would not be critical if such investor would buy the asset at time period t and sell it at t+ 1. Kallianiotis (1985) and Taylor (1995) furnish reviews of the literature on exchange rate economics and Chinn and Meese (1995) examine the performance of four structural exchange rate models.

This paper is organized as follows. Different trend models are described in section 2 and other linear time-series models are presented in section 3. The empirical results are given in section 4 with a summary of the findings presented near the conclusion of the paper in section 5.

2. TIME-SERIES TRENDS

One way to predict the variance of any time series is to explicitly introduce an independent variable that helps forecast the series' volatility. Consider a very simple case, in which

$$s_{t+1} = \varepsilon_{t+1} X_t \quad (1)$$

where s_{t+1} = the spot exchange rate (the variable of interest), ε_{t+1} = a white-noise disturbance term with variance σ^2, and X_t = an independent variable that can be observed at time period t. (If X_t = X_{t-1} = X_{t-2} = … = constant, then the $\{s_t\}$ sequence is a standard white-noise process with a constant variance.)

If the realizations of the $\{X_t\}$ sequence are not all equal, then the variance of s_{t-1} that is conditional on the observable value of X_t is:

$$Var\ (s_{t+1}\ /X_t) = X_t^2\sigma^2 \quad (2)$$

One may represent the general solution to a linear stochastic difference equation with the following four components:

$$s_t = trend + cyclical + seasonal + irregular$$

Exchange rate series do not have an apparent and noticeable tendency of reversion to a mean. One task of an econometrician is the formation of clear stochastic difference equation models that can simulate the behavior of trending variables, with such trends defined by their permanent effects on time series. Because the irregular component of a series is stationary, its effects will diminish as the trending elements and those elements' effects will persist in long-term forecasts.

Deterministic Trends

One of s_t's basic characteristics is long-term growth, despite its short-term volatility. In fact, s_t may have a long-term trend that is very apparent and well-defined. According to Pindyck and Rubinfeld (1981), Chatfield (1985), and Enders (1995), there are a minimum of eight models that describe this deterministic trend that can be used in extrapolating and forecasting s_t. They are:

Linear time trend:

$$S_t = \alpha_0 + \alpha_1 t + \varepsilon_t \quad (3)$$

Exponential growth curve:

$$S_t = \mathrm{A}e^{rt} \quad (4)$$

or

$$\ln S_t = \ln \mathrm{A} + \mathrm{rt} + \varepsilon_t \quad (5)$$

or

$$s_t = \beta_0 + \beta_1 t + \varepsilon_t \quad (6)$$

Logarithmic / stochastic autoregressive trend (the only function to be applied for exchange rates):

$$s_t = \gamma_0 + \gamma_1 s_{t-1} + \varepsilon_t \quad (7)$$

Quadratic trend:

$$s_t = \delta_0 + \delta_1\, t + \delta_2 t^2 + \varepsilon_t \quad (8)$$

Polynomial time trend:

$$s_t = \zeta_0 + \zeta_1 t + \zeta_2 t^2 + \ldots + \zeta_n t^n + \varepsilon_t \quad (9)$$

Logarithmic growth curve:

$$s_t = 1 / (\theta_0 + \theta_1 \theta_2^t); \quad \theta_2 > 0 \tag{10}$$

or a stochastic approximation of equation (10):

$$(\Delta s_t / s_{t-1}) = k_0 - k_1 s_{t-1} + \varepsilon_t \tag{11}$$

Sales saturation pattern:

$$S_t = e^{\lambda_0 - (\frac{\lambda_1}{t})} \tag{12}$$

or

$$s_t = \lambda_0 - (\lambda_1 / t) + \varepsilon_t \tag{13}$$

where S_t = the spot exchange rate, t = time trend, and the lowercase letters are the natural logarithms of their uppercase counterparts.

Models of Stochastic Trend

One may supplement the deterministic trend models with the lagged values of the $\{s_t\}$ and $\{\varepsilon_t\}$sequences. These equations become models with their own stochastic trends. The models used here are:

(i) The Random Walk Model

The random walk model – technically, a special case of the AR(1) process -- appears to imitate the exchange rates' behavior as shown below. These series neither fluctuate over time nor revert to any given mean.

$$s_t = \alpha_0 + \alpha_1 s_{t-1} + \varepsilon_t \tag{14}$$

with α_0 = 0 and α_1 = 1, where s_t - s_{t-1} = Δs_t = ε_t, becomes

$$s_t = s_{t-1} + \varepsilon_t \tag{15}$$

The conditional mean of $s_{t+\lambda}$ for any λ > 0 is

$$E_t S_{t+\lambda} = S_t + \mathrm{E}\textstyle\sum_{i=1}^{\lambda} \varepsilon_{t+i} = s_t \tag{16}$$

The variance is time-dependent:

$$\mathrm{var}\ (s_t) = \mathrm{var}\ (\varepsilon_t + \varepsilon_{t-1} + \ldots + \varepsilon_1) = \mathrm{t}\sigma^2 \tag{17}$$

The random walk process is nonstationary because the variance is not constant. Therefore, as

$$\mathrm{t} \rightarrow \infty, \mathrm{var}(s_t) \rightarrow \infty. \tag{18}$$

the forecast function will be:

$$E_t s_{t+\lambda} = s_t \tag{19}$$

(ii) The Random Walk plus Drift Model

The random walk plus drift model adds a constant term α_0 to the random walk model described earlier such that s_t becomes partly deterministic and partly stochastic.

$$s_t = s_{t-1} + \alpha_0 + \varepsilon_t \tag{20}$$

The general solution for s_t is:

$$s_t = s_0 + \alpha_0 t + \sum_{i=1}^{t} \varepsilon_i \quad (21)$$

and

$$E_t s_{t+\lambda} = s_0 + \alpha_0 (t + \lambda) \quad (22)$$

The forecast function by λ periods yields

$$E_t s_{t+\lambda} = s_t + \alpha_0 \lambda \quad (23)$$

(iii) The Random Walk plus Noise Model

The s_t in this case is the sum of a stochastic trend and a white-noise component

$$s_t = \mu_t + n_t \quad (24)$$

and

$$\mu_t = \mu_{t-1} + \varepsilon_t \quad (25)$$

where $\{n_t\}$ is a white-noise process with variance σ_n^2 and n_t and ε_t are both independently distributed for all t.

E($\varepsilon_t \, n_{t-\lambda}$) = 0; the $\{\mu_t\}$ sequence represents the stochastic trend. The solution for this model is:

$$s_t = s_0 - n_0 + \sum_{i=1}^{t} \varepsilon_i + n_t \quad (26)$$

The forecast function is:

$$E_t S_{t+\lambda} = s_t - n_t \quad (27)$$

(iv) The General Trend plus Irregular Model

One may replace equation (25) above with the so-called "trend plus noise model,"

$$\mu_t = \mu_{t-1} + \alpha_0 + \varepsilon_t \quad (28)$$

where α_0 is a constant and $\{\varepsilon_t\}$ is a white-noise process.

The solution is:

$$s_t = s_0 - n_0 + \alpha_0 t + \sum_{i=1}^{t} \varepsilon_i + n_t \quad (29)$$

Let A(L) be a polynomial in the lag operator L. It is possible to augment a random walk plus drift process with the stationary noise process A(L) n_t and obtain the following "general trend plus irregular model":

$$s_t = \mu_0 + \alpha_0 t + \sum_{i=1}^{t} \varepsilon_i + A(L)\, n_t \quad (30)$$

(v) The Local Linear Trend Model

The local linear trend model comprises several random walk plus noise processes. Let $\{\epsilon_t\}$, $\{n_t\}$, and$\{u_t\}$ be three mutually uncorrelated white-noise processes such that the equations for the local linear trend model are:

$$s_t = \mu_t + n_t$$
$$\mu_t = \mu_{t-1} + \alpha_t + \varepsilon_t \quad (31)$$
$$\alpha_t = \alpha_{t-1} + u_t$$

This is the most detailed out of all the models above because the other processes are special cases of the local linear trend model consisting of the noise term n_t and the stochastic trend term μ_t. What is most important about the model in this paper is that the change in the model's trend yields a random walk plus noise:

$$\Delta\mu_t = \mu_t - \mu_{t-1} = \alpha_t + \varepsilon_t \quad (32)$$

The forecast function of $s_{t+\lambda}$ equals the current value of s_t minus the transitory component n_t, added to λ multiplied by the slope of the trend term in t:

$$E_t s_{t+\lambda} = (s_t - n_t) + \lambda\,(\alpha_0 + u_1 + u_2 + \ldots + u_t) \quad (33)$$

A future researcher may estimate all these models and run different tests on the series and the error terms and thus obtain both specification and diagnostic tests as a way of gauging the statistical specifications' adequacy. The forecasting results from these different models could then be compared.

3. SOME LINEAR TIME-SERIES MODELS

In this section, stochastic processes are defined and some of their properties are discussed in forecasting, with a view toward developing models that explain the movement of time series s_t. However, this will not be done using a set of explanatory variables as was done in the regression model but by relating it to both its own past values and a weighted sum of lagged and current random disturbances.

The Autoregressive (AR) Model

In the autoregressive process of order p, the current observation s_t is generated by a weighted average of past observations going back p periods together with the current period t's random disturbance. This process is called AR(p) and its equation is:

$$s_t = \phi_1 s_{t-1} + \phi_2 s_{t-2} + \ldots + \phi_p s_{t-p} + \delta + \varepsilon_t \quad (34)$$

δ is a constant term which relates to the mean of the stochastic process.

The first-order process AR(1) is:

$$s_t = \phi_1 s_{t-1} + \delta + \varepsilon_t \quad (35)$$

Its mean is:

$$\mu = \delta / (1 - \phi_1) \quad (36)$$

and is stationary if $|\phi_1| < 1$. (However, the random walk with drift is a first-order autoregressive process that is not stationary.)

4. EMPIRICAL EVIDENCE

A summary and analysis of the empirical evidence of different models of foreign currency forecasting is included below. The data are monthly from March 1973 through December 1994 inclusive, coming from *Main Economic Indicators* of the OECD (the Organization for Economic Cooperation and Development) and *International Financial Statistics* of the IMF (the International Monetary Fund), and have been applied for Canada. The exchange rate is defined as the U.S. dollar per Canadian dollar, with direct quotes for the U.S. dollar. The lowercase letters denote the natural logarithm of the variables and an asterisk denotes the corresponding variable for Canada.

The first equations estimated are the deterministic trend models in equations (3), (6), (8), (9), (11), and (13). The results appear in Table 1 below and indicate that the exchange rate forecast cannot be supported by models of this type. The second group is the stochastic trend model in equations (15) and (20); these results, in Table 2, show that this alternative model is much better at both interpreting the data and forecasting the exchange rate. The final model is of a linear time-series, the autoregressive (AR) model of equation (34) in Table 3, but its results are also poor. One may infer that time-series models cannot be used in forecasting foreign currency exchange rates with a great degree of faith or assurance for models having such relatively high volatility.

Table 1. Deterministic trends

(i) Linear time trend, eq. (3): $S_t = \alpha_0 + \alpha_1 t + \varepsilon_t$		(ii) Exponential Growth Curve, eq. (6): $s_t = \beta_0 + \beta_1 t + \varepsilon_t$	
α_0	98. 279***	$ß_0$	4.588***
	(.912)		(.011)
α_1	-.086***	$ß_1$	-.001***
	(.005)		(6.0-05)
R^2	.502	R^2	.486
D-W	.031	D-W	.031
SSR	10,166.36	SSR	1.396
F	256.270	F	240.45
RMSE	6.3018	RMSE	.0738
(iii) Quadratic Trend, eq. (8): $s_t = \delta_0 + \delta_1 t + \delta_2 t^2 + \varepsilon_t$		(iv) Polynomial time trend, eq. (9): $s_t = \zeta_0 + \zeta_1 t + \zeta_2 t^2 + \ldots + \zeta_n t^n + \varepsilon_t$	
δ_0	4.773***	ζ_0	3.221***
	(.015)		(.148)
δ_1	-.004***	ζ_1	.107***
	(.0002)		(.011)
δ_2	1.0-05***	ζ_2	-.003***
	(7.0-07)		(.0003)
		ζ_3	4.0-05***
			(4.0-06)
		ζ_4	-3.0-07***
			(3.0-08)
		ζ_5	1.0-09***
			(1.0-10)
		ζ_6	-3.0-12***
			(3.0-13)
		ζ_7	3.0-15***
			(3.0-16)
R^2	.720	R^2	.937
D-W	.057	D-W	.246
SSR	.761	SSR	.170
F	325.06	F	529.49
RMSE	.0545	RMSE	.0258
(v) Stochastic approximation, eq. (11): $(\Delta s_t / s_{t-1}) = k_0 - k_1 s_{t-1} + \varepsilon_t$		(vi) Sales Saturation Pattern, eq. (13): $s_t = \lambda_0 - (\lambda_1 / t) + \varepsilon_t$	
k_0	.037	λ_0	4.334***
	(.035)		(.007)
k_1	-.009	λ_1	11.202***
	(.008)		(.566)
R^2	.005	R^2	.606

D-W	2.091	D-W	.042
SSR	.043	SSR	1.069
F	1.230	F	391.42
RMSE	.0129	RMSE	.0646

Note. S_t = the spot exchange rate, s_t = ln(S_t), t = time, D-W = the Durbin-Watson statistic, SSR = sum of squares residuals, RMSE = root mean square error, Data from 1973.03 to 1994.06, $***$ = significant at the 1% level, $**$ = significant at the 5% level, $*$ = significant at the 10% level. Δ = change of the variable.

Table 2. Stochastic trends

(i) The Random Walk Model, eq. (15): $s_t = s_{t-1} + \varepsilon_t$		(ii) The Random Walk plus Drift Model, eq. (20): $s_t = \alpha_1 s_{t-1} + \alpha_0 + \varepsilon_t$	
s_{t-1}	1.000***	α_0	.037
	(.0002)		(.035)
		α_1	.991***
			(.008)
R^2	.984	R^2	.984
D-W	2.100	D-W	2.091
SSR	.043	SSR	.043
L(.)	749.05	F	15,838.51
RMSE	.0130	RMSE	.0129

Note. See the previous table. L(.) = log of likelihood function.

Table 3. Linear time-series models

The Autoregressive (AR) Model, eq. (34): $s_t = \phi_1 s_{t-1} + \phi_2 s_{t-2} + \ldots + \phi_p s_{t-p} + \delta + \varepsilon_t$	
δ	4.371***
	(.071)
ϕ_1	.898***
	(.063)
ϕ_2	.011
	(.085)
ϕ_3	.089
	(.085)
ϕ_4	.041
	(.086)
ϕ_5	.008
	(.085)
ϕ_6	-.103
	(.085)
ϕ_7	.005
	(.085)
ϕ_8	.184**
	(.085)
ϕ_9	-.025
	(.086)
ϕ_{10}	.010
	(.086)
ϕ_{11}	.049
	(.087)
ϕ_{12}	.181***
	(.064)
R^2	.986
$D-W$	1.975
SSR	.039
F	1,385.98
$RMSE$	.0124

Note. See the previous tables.

5. SUMMARY

This paper examines the predictive performance of exchange rate forecasting models such as linear time-series, the vector autoregression model, and various time-series trends. For every such model, the RMSE is calculated as:

$$\text{RMSE} = \sqrt{\left(\sum_{t=1}^{n} (A_t - F_t)^2\right) / n}$$

where n = the number of observations, A = the actual value of the dependent variable, and F = the forecast value. The forecast model with the smallest RMSE is the best predictor for foreign exchange rate forecasting.

An exchange rate is the relative price of two countries' currencies. The most crucial factors that determine a country's currency value relate to the differences in inflation, the relative money supplies, real incomes, and prices, and interest rate, trade balance and budget deficit differentials. There is some good fit in the models we have presented, but there is still room for improvement in foreign currency forecasts' current mathematical models. Exchange rate movements themselves may result from either a parametric change in the above determinants or an artificial intervention by governments.

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