THE UNIVERSITY OF MELBOURNE

DEPARTMENT OF ECONOMICS

GROUP PROJECT COVER SHEET

SUBJECT CODE:	**SUBJECT NAME:**
ECOM30004	Time Series Analysis and Forecasting
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GROUP WEIGHTS

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Signed: Joel Thomas, Rohini Poonyth Date: 26/09/2019

The Decline of the Australian Exchange Rate

Section 1: Introduction

An exchange rate also known as a Forex rate is the value of one country's currency in terms of another country's currency (RBA, 2019). It is one of the key determinants of economic growth for most developed countries. Articles from news sources Small Caps (Cullinane, 2019) and Australian Financial Review (Boyd, Poljak, Moore, 2019) reported the decline of the Australian currency which hit its lowest point in a decade in January 2019 at that time and in August 2019. Both Small Caps and Capital Economics, a leading economic research firm, are forecasting a continuing decline of the AUD with the latter predicting the Australian-US dollar to drop to $0.60 by the end of 2019 (Scott, 2019). The aim is to assess those predictions since the AUD exchange rate affect a country in a number of ways (RBA, 2019):

- Consumers purchase goods and services from other countries e.g. international students studying at university, an example of education exports
- Exchange rate is a key consideration for most developed central banks setting monetary policy.
- Potential impact on economic growth through net exports which is a component of GDP – effect on economic growth.

The purpose of this report is to use time series analysis to analyse the impact of key factors involved in the constant depreciation in the value of the Australian exchange rate (AUD) against several other currencies since the start of 2011. The start date was determined carefully because the Reserve Bank of Australia has never increased Australia's cash rate since this date.

The uncovered interest rate parity condition is a theory that states that at a given time, domestic interest rate (i_t) is linked to a foreign currency exchange rate (E_t) by the foreign country's interest rate (i_t^*) and expected foreign exchange rate (E_{t+1}^e) at the next time period (Hayes, 2019):

$$(1 + i_t) = (1 + i_t^*)\frac{E_t}{E_{t+1}^e}$$

In addition, an intuitive relationship exists between a country's exchange rate and net exports (Lioudis, 2019). As net exports (exports less imports) rise, higher demand for a country's goods increase demand for a country's currency as foreign individuals will need to buy domestic currency and sell foreign currency. Using the law of supply and demand, as demand for currency increases, buying pressure will lead to domestic currency appreciation. Hence combining the three theories, changes in interest rate differentials (difference in interest rates between two countries) and net exports should both have effects on a country's exchange rate.

By forecasting into the future using time series analysis, models will be analysed to identify long-term behaviour of exchange rates in the future while also evaluating any potential weaknesses or caveats of the final model and/or forecasts. We will also investigate the models to assess whether the theory agree with them.

Section 2: Data Description

The leading factors listed in the above-mentioned articles causing a downward pressure on the Australian currency were identified as interests rates, slowing growth, booming iron ore price and divergence in the policy of different governments (Cullinane, 2019).

For this report, the impact of interest rate differentials and the net exports of Australia will be used to assess predictability of Australia's exchange rate with the United States, New Zealand, Canada and Switzerland.

Retrieving the data was performed by using the popular programming language Python and some key libraries within it (Pandas and Pandas-data reader) to scrape the four exchange rates and interest rates and Australia's net exports position from sources including Quandl and FRED (Federal Reserve Economic Data). Both sources are web databases that store financial and economic datasets. Upon initially retrieving the data, some transformations were required to be made to arrive at the final dataset:

1) Frequency mismatch between currencies (daily data) and interest rate (month) – handled this by merging on interest rate dates so all data is monthly. The assumption is time series properties of a series deteriorate as the frequency of data increases (Mandelbrot, 1963). As there tends to be bigger spikes in volatility in daily currency rates relative to monthly rates, heavy tails on the extremes of the underlying distribution are often observed thereby affecting hypothesis test results which do not account for thicker tails (higher kurtosis). For example, using Python (SciPy), the kurtosis of daily AUDCAD **return** during the sample period is 1.051 > - 0.130 which is the kurtosis of monthly AUDCAD **return** (negative implies thinner tails). The same can be shown for other variables too. Temporal dependence – in addition to the above issue, it is assumed that serial autocorrelation is bigger if using daily data and hence the need to include more lags to nullify autocorrelation in the disturbance term. The solution to this is to include an MA model with infinite memory but this will only suffice if this is the type of the final model.

2) Date mismatch: sometimes, interest rates were recorded on weekends or other days when the foreign exchange market was closed. To deal with this issue, the first recorded future price of the exchange rates was backward filled (future to past) to match the Australian interest rate dates, including other interest rates if they did not previously match. The assumption is this will reveal the impact of the interest rate change on the foreign exchange market.

3) Interest rate differentials: interest rate differentials were calculated by subtracting a foreign country's interest rate from the domestic country's interest rate (i.e. the AUD) at each time period. Using interest rate differentials will yield results closer to theory than using raw interest rates as these will act as relative interest rates.

Descriptive Statistics									
	AUDUSD	**AUDNZD**	**AUDCAD**	**AUDCHF**	**AUS-US Interest Rate Diff.**	**AUS-NZ Interest Rate Diff.**	**AUS-CAN Interest Rate Diff.**	**AUS-CHF Interest Rate Diff.**	**AUS Net Exports**
Mean	0.860	1.138	0.993	0.811	1.914	0.178	1.298	3.125	-5372.713
Median	0.798	1.095	0.993	0.765	2.130	-0.170	1.250	2.830	-2925.000
Minimum	0.692	1.020	0.923	0.682	-0.920	-1.215	-0.500	2.350	-20174.00
Maximum	1.094	1.359	1.074	1.031	4.680	2.420	3.500	5.400	6388.000
Standard Deviation	0.131	0.096	0.036	0.096	1.640	0.990	1.140	0.802	8151.369
Skewness	0.402	0.863	0.175	0.577	-0.024	1.032	0.421	1.079	-0.391
Kurtosis	1.584	2.261	2.145	1.909	2.136	3.053	2.598	2.946	1.664
Observations	101	101	101	101	101	101	101	101	101

Table 1: Descriptive statistics of all variables used in analysis

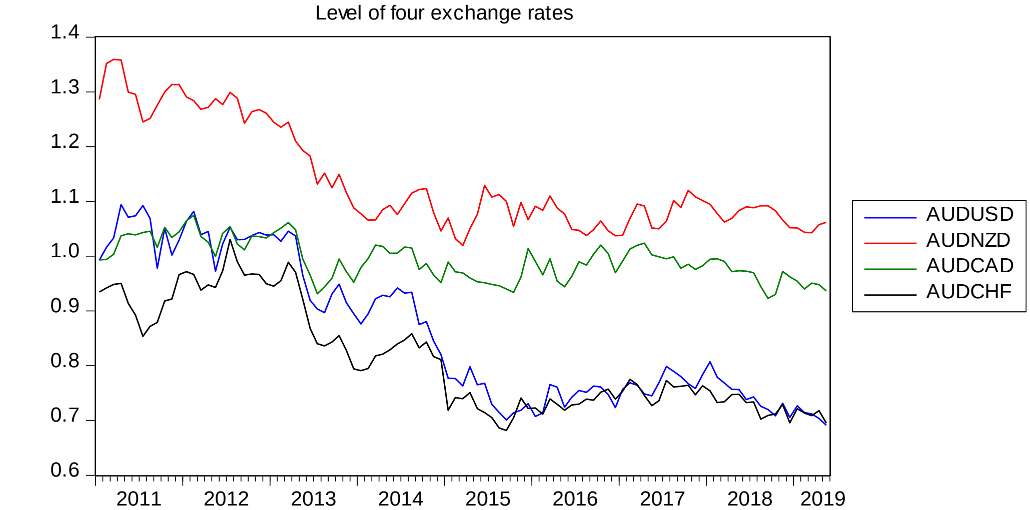

Figure 1: Time series plots of exchange rates

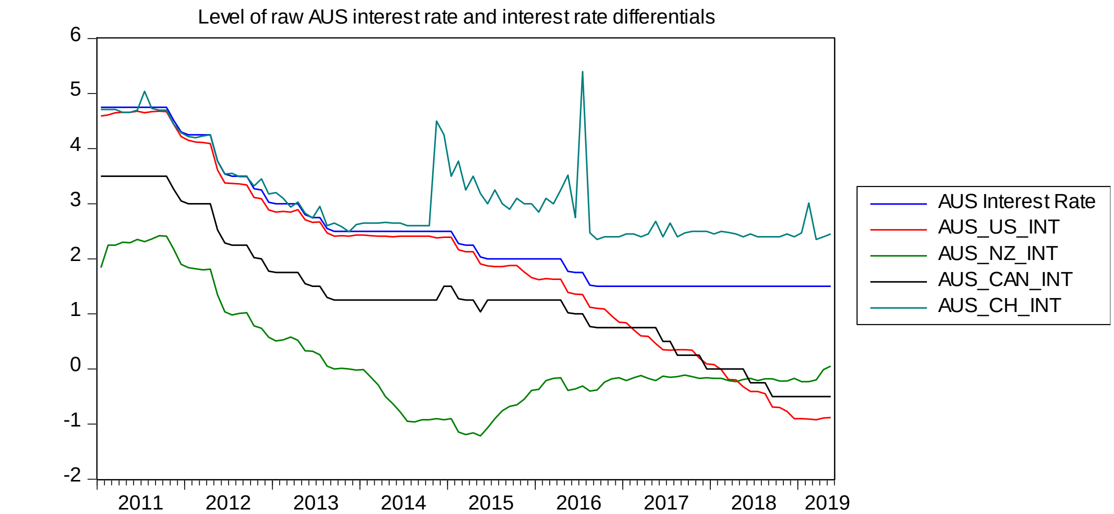

Figure 2: Time series plots of Australian interest rate and four interest rate differentials relative to Australia

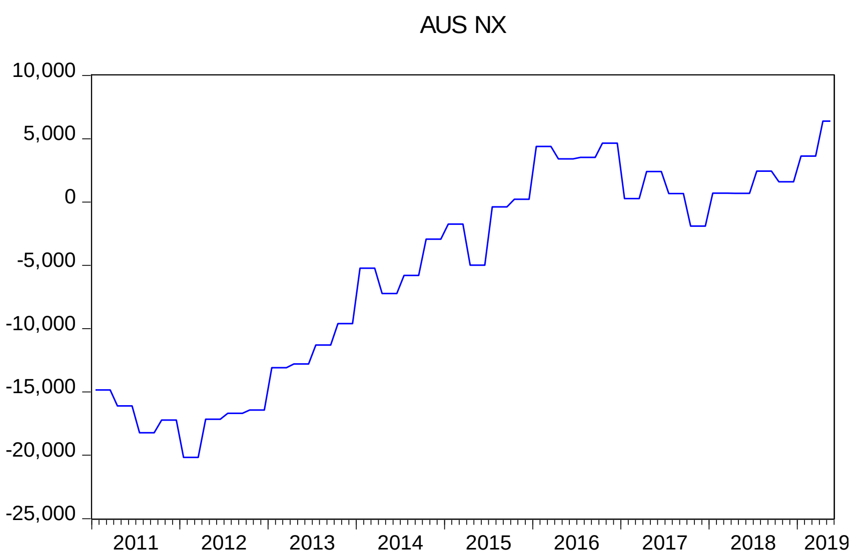

Figure 3: Time series plot of, Australia's net exports,

Using figures 1, there is evidence that all exchange rates except AUDCAD appear to trend downward over time suggesting non-stationarity in both the mean and the variance. AUDCAD appears to be non-stationary in the variance but stationary in the mean. Using figure 2-3, all interest rate differentials except the Australian-New Zealand interest rate appear to trend downward over time and appear non-stationary both in mean and variance.

The Australian-New Zealand interest rate appears to be stationary in the mean but non-stationary in the variance. The Australian-Switzerland interest rate does not appear to be stationary in the mean because it does not mean-revert. Australian net exports appear to have similar non-stationary properties as the currencies except it trends upwards.

AUDUSD:

Date: 09/22/19 Time: 12:17
Sample: 2011M01 2019M05
Included observations: 101

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.956	0.956	95.065	0.000
		2	0.902	-0.132	180.64	0.000
		3	0.841	-0.113	255.69	0.000
		4	0.791	0.128	322.84	0.000
		5	0.762	0.199	385.80	0.000
		6	0.737	-0.044	445.31	0.000
		7	0.725	0.106	503.43	0.000
		8	0.708	-0.031	559.43	0.000
		9	0.679	-0.123	611.62	0.000
		10	0.645	-0.022	659.22	0.000
		11	0.600	-0.078	700.84	0.000
		12	0.555	-0.049	736.83	0.000
		13	0.519	0.081	768.68	0.000
		14	0.484	-0.086	796.65	0.000
		15	0.453	-0.051	821.48	0.000
		16	0.420	-0.025	843.06	0.000
		17	0.386	-0.009	861.56	0.000
		18	0.354	-0.018	877.22	0.000
		19	0.320	0.017	890.21	0.000
		20	0.289	-0.016	900.92	0.000
		21	0.257	-0.035	909.53	0.000
		22	0.218	-0.121	915.81	0.000
		23	0.175	-0.085	919.87	0.000
		24	0.135	0.068	922.32	0.000
		25	0.102	0.044	923.74	0.000
		26	0.076	-0.017	924.55	0.000
		27	0.048	-0.094	924.87	0.000
		28	0.020	-0.019	924.93	0.000
		29	-0.001	0.100	924.93	0.000
		30	-0.025	-0.043	925.02	0.000
		31	-0.050	-0.037	925.40	0.000
		32	-0.077	0.018	926.29	0.000
		33	-0.097	0.066	927.73	0.000
		34	-0.115	-0.079	929.79	0.000
		35	-0.125	0.086	932.25	0.000
		36	-0.134	-0.011	935.11	0.000

AUDNZD:

Date: 09/22/19 Time: 12:13
Sample: 2011M01 2019M05
Included observations: 101

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.965	0.965	96.850	0.000
		2	0.934	0.043	188.51	0.000
		3	0.902	-0.032	274.81	0.000
		4	0.869	-0.019	355.87	0.000
		5	0.839	0.012	432.17	0.000
		6	0.814	0.055	504.64	0.000
		7	0.775	-0.204	571.03	0.000
		8	0.744	0.080	632.91	0.000
		9	0.716	0.040	690.82	0.000
		10	0.684	-0.068	744.30	0.000
		11	0.659	0.065	794.44	0.000
		12	0.631	-0.059	840.99	0.000
		13	0.599	-0.045	883.35	0.000
		14	0.571	0.018	922.36	0.000
		15	0.547	0.032	958.57	0.000
		16	0.519	-0.036	991.58	0.000
		17	0.500	0.059	1022.5	0.000
		18	0.476	-0.046	1051.0	0.000
		19	0.448	-0.075	1076.4	0.000
		20	0.421	-0.028	1099.1	0.000
		21	0.388	-0.111	1118.7	0.000
		22	0.349	-0.093	1134.7	0.000
		23	0.314	-0.024	1147.8	0.000
		24	0.279	0.016	1158.3	0.000
		25	0.241	-0.048	1166.3	0.000
		26	0.207	-0.037	1172.2	0.000
		27	0.172	0.012	1176.3	0.000
		28	0.139	0.011	1179.1	0.000
		29	0.110	-0.009	1180.9	0.000
		30	0.083	0.001	1181.8	0.000
		31	0.058	0.061	1182.4	0.000
		32	0.039	0.019	1182.6	0.000
		33	0.016	-0.053	1182.6	0.000
		34	-0.007	-0.015	1182.6	0.000
		35	-0.026	-0.011	1182.7	0.000
		36	-0.043	0.038	1183.0	0.000

AUDCAD:

Date: 09/22/19 Time: 12:19
Sample: 2011M01 2019M05
Included observations: 101

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.830	0.830	71.698	0.000
		2	0.663	-0.085	117.86	0.000
		3	0.569	0.138	152.25	0.000
		4	0.503	0.024	179.33	0.000
		5	0.451	0.043	201.33	0.000
		6	0.422	0.071	220.88	0.000
		7	0.371	-0.070	236.07	0.000
		8	0.315	-0.001	247.17	0.000
		9	0.278	0.015	255.88	0.000
		10	0.243	-0.016	262.65	0.000
		11	0.203	-0.025	267.43	0.000
		12	0.166	-0.022	270.67	0.000
		13	0.148	0.038	273.26	0.000
		14	0.174	0.136	276.88	0.000
		15	0.176	-0.053	280.64	0.000
		16	0.147	-0.041	283.29	0.000
		17	0.089	-0.111	284.26	0.000
		18	0.030	-0.054	284.37	0.000
		19	0.022	0.096	284.43	0.000
		20	0.032	-0.011	284.57	0.000
		21	0.005	-0.093	284.57	0.000
		22	-0.049	-0.086	284.89	0.000
		23	-0.092	-0.024	286.00	0.000
		24	-0.082	0.129	286.91	0.000
		25	-0.079	-0.057	287.77	0.000
		26	-0.058	0.092	288.23	0.000
		27	-0.054	-0.036	288.65	0.000
		28	-0.062	-0.014	289.20	0.000
		29	-0.064	0.007	289.79	0.000
		30	-0.065	-0.064	290.40	0.000
		31	-0.055	0.071	290.86	0.000
		32	-0.019	0.131	290.91	0.000
		33	0.017	0.030	290.96	0.000
		34	0.029	-0.053	291.09	0.000
		35	0.060	0.056	291.65	0.000
		36	0.049	-0.110	292.04	0.000

AUDCHF:

Date: 09/22/19 Time: 12:21
Sample: 2011M01 2019M05
Included observations: 101

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.957	0.957	95.360	0.000
		2	0.914	-0.038	183.05	0.000
		3	0.866	-0.061	262.74	0.000
		4	0.833	0.140	337.16	0.000
		5	0.803	0.023	407.09	0.000
		6	0.776	-0.001	473.05	0.000
		7	0.755	0.083	536.17	0.000
		8	0.726	-0.102	595.20	0.000
		9	0.692	-0.077	649.41	0.000
		10	0.648	-0.106	697.43	0.000
		11	0.615	0.102	741.17	0.000
		12	0.578	-0.088	780.29	0.000
		13	0.553	0.085	816.49	0.000
		14	0.530	0.019	850.06	0.000
		15	0.512	0.031	881.80	0.000
		16	0.483	-0.147	910.30	0.000
		17	0.450	0.004	935.33	0.000
		18	0.418	0.010	957.24	0.000
		19	0.379	-0.132	975.48	0.000
		20	0.348	0.032	991.02	0.000
		21	0.316	0.003	1004.0	0.000
		22	0.284	-0.143	1014.6	0.000
		23	0.261	0.157	1023.7	0.000
		24	0.232	-0.090	1030.9	0.000
		25	0.196	-0.117	1036.2	0.000
		26	0.156	-0.053	1039.6	0.000
		27	0.115	0.006	1041.4	0.000
		28	0.077	-0.063	1042.3	0.000
		29	0.044	-0.003	1042.6	0.000
		30	0.013	-0.006	1042.6	0.000
		31	-0.007	0.111	1042.6	0.000
		32	-0.028	-0.088	1042.7	0.000
		33	-0.057	-0.057	1043.2	0.000
		34	-0.082	0.101	1044.2	0.000
		35	-0.106	-0.033	1046.0	0.000
		36	-0.120	0.059	1048.3	0.000

Figure 4: Autocorrelation (ACF) and partial autocorrelation function (PACF) plots for currencies

ACFs and PACFS for only the key exchange rates are provided in figure 4 above because predictability of other variables is not of interest based on the project motivation outlined in Section 1. Using figure 4, there is evidence of strong dynamics in all the currencies. In the ACFs – it is observed that all variables except AUDCAD appear to decay linearly whereas AUDCAD decays exponentially. A slow decaying ACF is an indicator of non-stationarity in the mean as the mean tends to change over time (Salvi, 2019). In the PACFs – all variables have a single large statistically significant first lag. Using the PACF, which includes intermediate lags, AR (1) models are appropriate for the level of all four currencies. AR models are appropriate because given intermediate lags are included in the PACF, there is little or statistically insignificant correlation with the residuals and further lags and in general, the ACFs are decaying whereas the PACFs cut off sharply (Salvi, 2019). MA models would be inappropriate due to the same reason suggesting an infinite AR lag structure is not required (Salvi, 2019). However, if a series is statistically tested to be non-stationary i.e. under an AR(1) model, the slope coefficient on the first lag is not statistically different from 1, then no long-run equilibrium (or natural level) in levels can be found using this model because it does not exist.

Section 3: Empirical Methodology

Initially, unit root tests must be conducted on all variables to statistically identify non-stationarity in the series rather than using visual identification based on plots. This will also help identify the integrated order (number of differences required to make a series stationary, represented by I()) of the variables. A unit root test can be performed by using the Augmented Dickey-Fuller (ADF) test which accounts for the fact that the disturbance term u_t in the DF regression equation can exhibit autocorrelation. The log filter will also be used only on the exchange rates to capture non-linearities and attempt to make the series stationary in the variance as the log filter cannot be applied to other series which are negative at some points in time. The ADF equation is:

$ADF: y_t - y_{t-1} = \phi_0 + (\phi_1 - 1)y_{t-1} + \sum_{i=1}^{p} \gamma_i (y_{t-i} - y_{t-i-1}) + u_t$ where:

y_t is a dependent variable

ϕ_0 is the intercept

$\phi_1 - 1$ is the slope coefficient on which null hypothesis testing is done

γ_i are the slope coefficients of the included lags to correct for autocorrelation in u_t

p is the optimal lag order determined by Schwarz criterion

u_t is the disturbance term

$Hypothesis\ testing$:

$H_0: \phi_1 - 1 = 0 \rightarrow (non - stationary\ series)$

$H_1: \phi_1 - 1 < 0 \rightarrow (stationary\ series)$

where:

the underlying distribution of the ADF t-statistic is the DF distribution (negatively skewed)

Next, if the series are concluded to be I(1) or higher based on unit roots, the existence of a dynamic long-run equilibrium that changes continually but is characterized by the processes being attracted to each other may be identified by cointegration testing. If higher order non-stationary integrated processes are combined to generate a process with a lower order integration, this is evidence of cointegration. A cointegrating relation equation is given by:

$y_{1t} = \beta_0 + \beta_1 y_{2t} + \beta_2 y_{3t} + e_t$ where:

y_{1t} is the exchange rate

y_{2t} is the respective interest rate differential for that exchange rate

y_{3t} is Australian net exports

e_t is the disturbance term that must be stationary but can exhibit autocorrelation

The disturbance term must be (mean) stationary for a cointegration relationship to exist. The optimal lag structure to account for existing autocorrelation is $p-1$ where p denotes the optimal lag structure for a Vector Autoregressive (VAR) model, this is explained in detail below. If the variables are I(1), the Johansen cointegration test can be used which is a multivariate generalisation of a unit root test where the null/alternative hypotheses are I(1) vs. I(0) with the difference being inclusion of intermediate cases arising from presence of cointegration. Based on the theory in Section 1, cointegrated relationships are expected between a currency, its interest rate differential and the Australian net exports. The sequence of hypotheses for a trivariate system are:

$$Stage\ 1: \begin{cases} H_0: No\ cointegration - all\ variables\ are\ I(1) \\ H_1: At\ least\ one\ cointegrating\ equation \end{cases}$$

$$Stage\ 2: \begin{cases} H_0: At\ most\ one\ cointegration\ equation \\ H_1: At\ least\ two\ cointegrating\ equations \end{cases}$$

$$Stage\ 3: \begin{cases} H_0: At\ most\ two\ cointegration\ equations \\ H_1: All\ variables\ stationary - I(0) \end{cases}$$

If cointegration relationships are established between certain currencies and the respective interest rate differentials and Australian NX, then the dynamics around the long-run cointegrating equation given the variables are constantly evolving over time can be modelled using a Vector Error-Correction Model (VECM). If there are no relationships, a VAR model on the appropriate integrated order and optimal lag order suggested by a majority vote with the Schwarz and Hannan-Quinn criteria will be estimated. It is important that all variables in the VAR system have the same integrated order otherwise the model will be used to explain information that is non-stationary by a set of regressors that are stationary (Parker). A VECM may have an advantage as it may improve the precision of the forecasts by reducing the number of parameters in an unrestricted VAR. The trivariate model structures are:

$VECM(p-1): y_{1t} = \beta_0 + \beta_1 y_{2t} + \beta_2 y_{3t} + e_t$ where:

y_{1t} is the exchange rate

y_{2t} is the respective interest rate differential for that exchange rate

y_{3t} is Australian net exports

e_t is the disturbance term that must be stationary but can exhibit autocorrelation

VECM dynamic adjustment equations:

$$\Delta y_{1t} = \alpha_1 + \gamma_1 e_{t-1} + \sum_{i=1}^{p} \pi_i (y_{1t-i} - y_{1t-i-1}) + v_{1t}$$

$$\Delta y_{2t} = \alpha_2 + \gamma_2 e_{t-1} + \sum_{i=1}^{p} \delta_i (y_{2t-i} - y_{2t-i-1}) + v_{2t}$$

$\Delta y_{3t} = \alpha_3 + \gamma_3 e_{t-1} + \sum_{i=1}^{p} \omega_i (y_{3t-i} - y_{3t-i-1})\, v_{3t}$ where:

$\Delta y_{1t}, \Delta y_{2t}, \Delta y_{3t}$ are the first differences of the exchange rate, respective interest rate differential and net exports

α_i represents the equation intercept for $i \in [1,3]$

$v_t = (v_{1t}, v_{2t}, v_{3t})'$ and $v_t \sim N(0, \Omega)$ and each v_{it} may be assumed to be white noise (optimal lag order will correct for autocorrelation)

$p-1$ is the optimal VECM lag structure based on optimal VAR lag structure for the equivalent system

$VAR(p)$: $y_t = \Phi_0 + \Phi_1 y_{t-1} + \Phi_2 y_{t-2} + \cdots + \Phi_p y_{t-p} + u_t$ where:

y_t is a (3×1) containing the exchange rate, respective interest rate differential and net exports

Φ_0 is a (3×1) vector of constants

Φ_i are (3×3) matrices of AR parameters for $i \in [1,3]$

u_t is a (3×1) vector of disturbances and each $u_{it} \sim N(0, \sigma_u)$ and is white noise

p is the optimal VAR lag structure based on majority vote with the Schwarz and Hannan-Quinn criteria

Using the optimal models, ex-ante forecasts will be generated to predict the long-term forecast for each currency.

Section 4: Empirical Results

The Augmented Dickey-Fuller unit root test results for all variables are illustrated in the tables below:

	Level of log(AUDUSD)	Level of log(AUDNZD)	Level of log(AUDCAD)	Level of log(AUDCHF)
Optimal lag order	1	1	1	1
Slope coefficients estimate	-0.016	-0.039	-0. 149	-0.028
ADF t-statistic ($\hat{\phi}_1 - 1$)	-0.795	-1.590	-2.689	-1.181
p-value	0.816	0.484	0.08	0.6802
Null hypothesis (at 5% level)	Fail to reject → evidence of non-stationarity	Fail to reject → evidence of non-stationarity	Fail to reject → evidence of non-stationarity	Fail to reject → evidence of non-stationarity

Table 2: ADF unit root tests for level of currencies

	First difference of log(AUDUSD)	First difference of log(AUDNZD)	First difference of log(AUDCAD)	First difference of log(AUDCHF)
Optimal lag order	1	1	2	1
Slope coefficient estimate (second row = second coefficient)	-1.110	-1.047	-1.223 0.235	-0.998
ADF t-statistic ($\hat{\phi}_1 - 1$)	-11.037	-10.693	-8.707	-9.785
p-value	0	0	0	0
Null hypothesis (at 5% level of significance)	Reject the null → evidence of stationarity	Reject the null → evidence of stationarity	Reject the null → evidence of stationarity	Reject the null → evidence of stationarity

Table 3: ADF unit root test results confirming stationarity in first difference of currencies

	Level of AUS_US_INT	Level of AUS_NZ_INT	Level of AUS_CAN_INT	Level of AUS_CH_INT	Level of AUS_NX
Optimal lag order	1	2	1	2	1
Slope coefficients estimate	-0.000249	-0.026 0.345	-0.011	-0.135 -0.423	-0.010
ADF t-statistic ($\hat{\phi}_1 - 1$)	-0.045	-2.666	-1.159	-2.410	-0.598
p-value	0.951	0.0837	0.690	0.142	0.865
Null hypothesis (at 5% level of significance)	Fail to reject → evidence of non-stationarity	Fail to reject → evidence of non-stationarity	Fail to reject → evidence of non-stationarity	Fail to reject → evidence of non-stationarity	Fail to reject → evidence of non-stationarity

Table 4: ADF unit root tests for level of interest rate differentials and AUS net exports

	First difference of AUS_US_INT	First difference of AUS_NZ_INT	First difference of AUS_CAN_INT	First difference of AUS_CH_INT	First difference of AUS_NX
Optimal lag order	1	1	1	2	1
Slope coefficients estimate	-0.886	-0.641	-0.976	-1.819 0.226	-1.025
ADF t-statistic ($\hat{\phi}_1 - 1$)	-8.791	-7.368	-9.612	-10.559	-10.103
p-value	0	0	0	0	0
Null hypothesis (at 5% level of significance)	Reject the null → evidence of stationarity	Reject the null → evidence of stationarity	Reject the null → evidence of stationarity	Reject the null → evidence of stationarity	Reject the null → evidence of stationarity

Table 5: ADF unit root test results confirming stationarity in first difference of interest rate differentials and AUS net exports

From tables 2-5, there is statistical evidence of non-stationarity in the level of all variables but evidence of stationarity in the first difference of all variables i.e. they are integrated to order 1. Thus, a VAR model is optimal in this case with all variables being I(1) in the case that a VECM model is inappropriate. Below, cointegration tests are performed to determine which model is appropriate by establishing the number of statistical cointegration relationships. Note that the residuals need not be graphed for visual evidence of stationarity because this is dealt with by the Johansen test itself.

		log(AUDUSD) regressed on AUS_US_INT and AUS_NX		log(AUDNZD) regressed on AUS_NZ_INT and AUS_NX		log(AUDCAD) regressed on AUS_CAN_INT and AUS_NX		log(AUDCHF) regressed on AUS_CH_INT and AUS_NX	
Optimal lag order of VECM to account for autocorrelation ($p-1$)		0		0		0		0	
		Trace statistic	**p-value**	**Trace statistic**	**p-value**	**Trace statistic**	**p-value**	**Trace statistic**	**p-value**
Hypothesised no. of CE(s):	**None**	26.267	0.121	39.253	0.003	25.445	0.146	37.435	0.005
	At most 1	3.102	0.962	12.790	0.123	8.553	0.408	12.363	0.140
	At most 2	0.021	0.884	3.454	0.063	0.017	0.194	0.444	0.505
Null hypothesis (at 5% level of significance)		Fail to reject at stage 1 → no cointegration		Fail to reject at stage 2 → at least one cointegrating equation		Fail to reject at stage 1 → no cointegration		Fail to reject at stage 2 → at least one cointegrating equation	
Optimal model decision		**VAR(1)**		**VECM(0)**		**VAR(1)**		**VECM(0)**	

Table 6: Johansen cointegration test results for all the currencies regressed on their respective interest rate differentials and Australian net exports. Unrestricted cointegration rank test (Trace) results used

In table 6, using p-values, it appears that there are no cointegration relationships for the AUDUSD and AUDCAD regressed on the Australia-US and Australia-Canada interest rate differentials respectively together with Australian net exports.

As a VECM model is inappropriate for these two cointegration relationships, a VAR(1) with all variables in first differences, based on unit root results and optimal VAR lag structure, is optimal for forecasting based on the reasoning provided in Section 3. Note that because both nulls failed to be rejected at stage 1, these are unlikely to imply spurious regressions because there is strong belief that the underlying variables in each equation are interconnected by economic theory. On the other hand, there are at most one cointegration relationships for both the AUDNZD and AUDCHF regressed on the Australia-New Zealand and Australia-Switzerland interest rate differentials respectively together with Australian net exports. This is due to failure to reject the null at stage 2 at the 5% level. Hence a VECM(0) model is appropriate for forecasting also based in the reasoning provided in Section 3. From the description of the theory, it is assumed that the cointegration relationships hold exactly in the form of the theoretical relationships and hence the VECM models are heavily based on these assumptions. Using these optimal model decisions from table 6, all output from the estimated models are illustrated below:

Vector Autoregression Estimates
Date: 09/25/19 Time: 15:33
Sample (adjusted): 2011M03 2019M05
Included observations: 99 after adjustments
Standard errors in ( ) & t-statistics in [ ]

	DLAUDUSD	DAUS_US_INT	DAUS_NX
DLAUDUSD(-1)	-0.084896	-0.040990	-5940.629
	(0.10202)	(0.31293)	(4745.80)
	[-0.83216]	[-0.13099]	[-1.25177]
DAUS_US_INT(-1)	-0.084840	0.117840	890.0728
	(0.03417)	(0.10483)	(1589.78)
	[-2.48253]	[1.12414]	[0.55987]
DAUS_NX(-1)	-2.52E-06	-7.72E-07	-0.058188
	(2.3E-06)	(6.9E-06)	(0.10490)
	[-1.11660]	[-0.11163]	[-0.55468]
C	-0.008339	-0.048908	255.6437
	(0.00353)	(0.01083)	(164.242)
	[-2.36181]	[-4.51610]	[1.55651]
R-squared	0.092062	0.013275	0.017737
Adj. R-squared	0.063390	-0.017885	-0.013282
Sum sq. resids	0.081274	0.764692	1.76E+08
S.E. equation	0.029249	0.089718	1360.649
F-statistic	3.210892	0.426034	0.571812
Log likelihood	211.2250	100.2635	-852.7894
Akaike AIC	-4.186364	-1.944717	17.30888
Schwarz SC	-4.081510	-1.839864	17.41373
Mean dependent	-0.003888	-0.055455	214.5051
S.D. dependent	0.030223	0.088927	1351.702

Determinant resid covariance (dof adj.)	11.26331
Determinant resid covariance	9.952481
Log likelihood	-535.1669
Akaike information criterion	11.05388
Schwarz criterion	11.36844
Number of coefficients	12

Vector Autoregression Estimates
Date: 09/25/19 Time: 15:35
Sample (adjusted): 2011M03 2019M05
Included observations: 99 after adjustments
Standard errors in ( ) & t-statistics in [ ]

	DLAUDCAD	DAUS_CAN_...	DAUS_NX
DLAUDCAD(-1)	0.021368	0.519347	688.7970
	(0.10058)	(0.51181)	(6716.53)
	[0.21246]	[1.01472]	[0.10255]
DAUS_CAN_INT(-1)	-0.025152	0.018307	1337.608
	(0.02013)	(0.10242)	(1344.01)
	[-1.24974]	[0.17875]	[0.99523]
DAUS_NX(-1)	-2.55E-06	-8.99E-07	-0.031863
	(1.5E-06)	(7.8E-06)	(0.10222)
	[-1.66866]	[-0.11542]	[-0.31172]
C	-0.001058	-0.039228	275.7079
	(0.00224)	(0.01140)	(149.624)
	[-0.47227]	[-3.44054]	[1.84268]
R-squared	0.046430	0.011419	0.011247
Adj. R-squared	0.016317	-0.019800	-0.019977
Sum sq. resids	0.039699	1.028034	1.77E+08
S.E. equation	0.020442	0.104026	1365.136
F-statistic	1.541876	0.365770	0.360206
Log likelihood	246.6916	85.61491	-853.1153
Akaike AIC	-4.902861	-1.648786	17.31546
Schwarz SC	-4.798007	-1.543933	17.42031
Mean dependent	-0.000600	-0.040404	214.5051
S.D. dependent	0.020611	0.103011	1351.702

Determinant resid covariance (dof adj.)	8.360251
Determinant resid covariance	7.387280
Log likelihood	-520.4128
Akaike information criterion	10.75582
Schwarz criterion	11.07038
Number of coefficients	12

Vector Error Correction Estimates
Date: 09/25/19 Time: 15:47
Sample (adjusted): 2011M02 2019M05
Included observations: 100 after adjustments
Standard errors in ( ) & t-statistics in [ ]

Cointegrating Eq:	CointEq1
LAUDNZD(-1)	1.000000
AUS_NZ_INT(-1)	-0.025265
	(0.00873)
	[-2.89287]
AUS_NX(-1)	8.31E-06
	(1.1E-06)
	[7.74826]
C	-0.076564

Error Correction:	D(LAUDNZD)	D(AUS_NZ_...	D(AUS_NX)
CointEq1	-0.198700	1.106171	-4341.307
	(0.06327)	(0.36321)	(4424.70)
	[-3.14070]	[3.04556]	[-0.98115]
C	-0.001914	-0.017900	212.3600
	(0.00192)	(0.01104)	(134.528)
	[-0.99495]	[-1.62095]	[1.57855]
R-squared	0.091449	0.086464	0.009728
Adj. R-squared	0.082178	0.077142	-0.000377
Sum sq. resids	0.036260	1.195073	1.77E+08
S.E. equation	0.019235	0.110429	1345.282
F-statistic	9.864013	9.275459	0.962661
Log likelihood	254.2167	79.45428	-861.3196
Akaike AIC	-5.044334	-1.549086	17.26639
Schwarz SC	-4.992230	-1.496982	17.31850
Mean dependent	-0.001914	-0.017900	212.3600
S.D. dependent	0.020078	0.114952	1345.029

Determinant resid covariance (dof adj.)	7.317114
Determinant resid covariance	6.886809
Log likelihood	-522.1620
Akaike information criterion	10.62324
Schwarz criterion	10.85770
Number of coefficients	9

Vector Error Correction Estimates
Date: 09/25/19 Time: 15:47
Sample (adjusted): 2011M02 2019M05
Included observations: 100 after adjustments
Standard errors in ( ) & t-statistics in [ ]

Cointegrating Eq:	CointEq1
LAUDCHF(-1)	1.000000
AUS_CH_INT(-1)	0.116638
	(0.02407)
	[4.84485]
AUS_NX(-1)	2.05E-05
	(2.4E-06)
	[8.57903]
C	-0.038675

Error Correction:	D(LAUDCHF)	D(AUS_CH_...	D(AUS_NX)
CointEq1	-0.044594	-2.008589	-5189.266
	(0.03471)	(0.59099)	(1647.21)
	[-1.28480]	[-3.39866]	[-3.15034]
C	-0.002955	-0.022600	212.3600
	(0.00271)	(0.04622)	(128.822)
	[-1.08858]	[-0.48897]	[1.64848]
R-squared	0.016565	0.105438	0.091959
Adj. R-squared	0.006530	0.096310	0.082693
Sum sq. resids	0.072207	20.93502	1.63E+08
S.E. equation	0.027144	0.462193	1288.217
F-statistic	1.650716	11.55087	9.924621
Log likelihood	219.7754	-63.70652	-856.9851
Akaike AIC	-4.355507	1.314130	17.17970
Schwarz SC	-4.303404	1.366234	17.23181
Mean dependent	-0.002955	-0.022600	212.3600
S.D. dependent	0.027233	0.486199	1345.029

Determinant resid covariance (dof adj.)	254.0118
Determinant resid covariance	239.0739
Log likelihood	-699.5202
Akaike information criterion	14.17040
Schwarz criterion	14.40487
Number of coefficients	9

Figure 5: Estimated output of VAR and VECM models based on the optimal model decision

Based on the VAR output for AUDUSD in figure 5 and our equations in section 3:

1. $\hat{\phi}_{1,11} = -0.0849$: Lagged return on AUDUSD affects current return negatively at lag 1 but the parameter estimate is statistically insignificant at 5%.
2. $\hat{\phi}_{1,12} = -0.0849$: The change in lagged interest rate differential between Australia and US affects the current return on AUDUSD negatively at lag 1 and the parameter estimate is statistically significant at 5% level. This is inconsistent with theory because a higher interest rate differential should lead to currency appreciation.
3. $\hat{\phi}_{1,13} = -2.52\mathrm{E}-06$: The change in lagged net exports of Australia affects the current return on AUDUSD negatively at lag 1 but this is statistically insignificant at 5% level. This is not inconsistent with theory as the coefficient simply means it is statistically indifferent to 0.

A possible reason why $\hat{\phi}_{1,12}$ is inconsistent with theory may be that the equation has been estimated imprecisely (too many lags) suggested by the fact that $\hat{\phi}_{1,11}$ and $\hat{\phi}_{1,13}$ are both statistically insignificant at the 5% level. A joint Wald test for the null that the return of AUDUSD is exogeneous can help reveal this. Regardless, this equation will still be used for ex-ante forecasting.

Based on the VAR output for AUDCAD on figure 5 and our equations in section 3:

1. $\hat{\phi}_{1,11} = 0.0214$: Lagged return on AUDCAD affects current return positively at lag 1 but the parameter estimate is statistically insignificant at 5%.
2. $\hat{\phi}_{1,12} = -0.0252$: The interest rate differential between Australia and Canada affects the return on AUDCAD negatively at lag 1 but the parameter estimate is statistically insignificant at 5%. This is not inconsistent with theory as the coefficient simply means it is statistically indifferent to 0.
3. $\hat{\phi}_{1,13} = -2.52\mathrm{E}-06$: Lagged net exports of Australia negatively affects the return on AUDCAD but this is statistically insignificant at 5% level. This is not inconsistent with theory as the coefficient simply means it is statistically indifferent to 0.

Based on the VECM equation in figure 5 on the assumed cointegration relationship for AUDNZD and its regressors:

- $\hat{\gamma}_1 = -0.199$: decreases exchange rate to restore equilibrium due to selling pressure at attractive prices (consistent with theory, statistically significant at 5% level)
- $\hat{\gamma}_2 = 1.106$: increases interest rate to restore equilibrium (inconsistent with theory, statistically significant at 5% level)
- $\hat{\gamma}_3 = -4341.307$: decreases net exports to restore equilibrium as when net exports decrease, there is higher (lower) demand for imports (exports). Lower demand for a currency leads to currency depreciation (consistent with theory, statistically insignificant at 5% level)

A possible reason why $\hat{\gamma}_2$ is inconsistent with theory may be because from figures 1 and 2 the AUDNZD appears to be trending downwards whereas the AUS-NZ interest rate differential appears to trend down in the first half and then trend up in the second half of the series, suggesting there are other important factors influencing the depreciation of the AUDNZD which are not accounted for in this project.

Based on the VECM equation in figure 5 on the assumed cointegration relationship for AUDCHF and its regressors:

- $\hat{\gamma}_1 = -0.045$: decreases exchange rate to restore equilibrium due to selling pressure at attractive prices (consistent with theory, statistically insignificant at 5% level)
- $\hat{\gamma}_2 = -2.009$: decreases interest rate to restore equilibrium as lower interest rate leads to currency depreciation (consistent with theory, statistically significant at 5% level)

- $\hat{\gamma}_3 = -5189.266$: decreases net exports to restore equilibrium as when net exports decrease, there is higher (lower) demand for imports (exports). Lower demand for a currency leads to currency depreciation (consistent with theory, statistically significant at 5% level)

Ex-ante forecasts are conducted below for all models to analyse the long-term trend over one year i.e. the forecast period is from June 2019 to June 2020. One year is considered to be long-term because exchange rates can be traded on secondly or even higher frequency data.

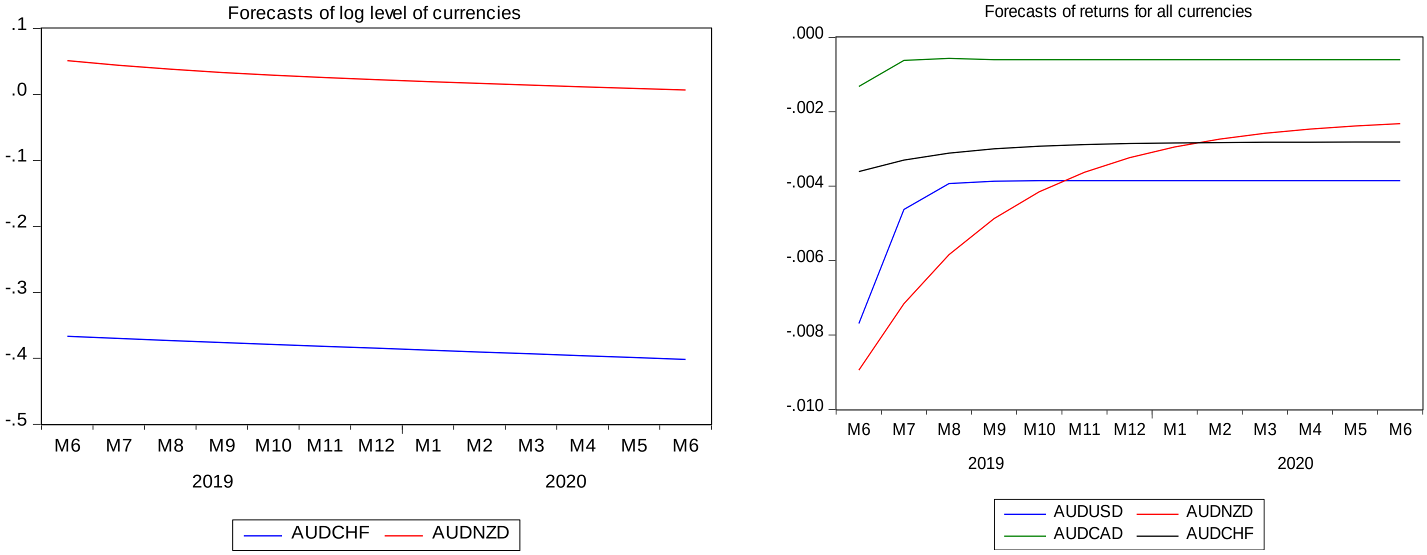

Figure 6: Forecasts of log levels and forecasts of returns for the currencies.

Using figure 6, As the VECM models' forecasts for AUDNZD and AUDCHF are in log levels, taking the first difference for both forecasted series will yield the forecasted returns which are plotted together with the VAR forecasts in the graph above. As all returns are expected to increase at a decreasing rate, this implies that the exchange rates are forecasted to decrease at a decreasing rate.

Relating back to the articles discussed in Section 1, it is evident that the project's findings are consistent with statements made by Small Caps and Capital Economics concerning the future decline of the AUD. Although Capital Economics explicitly makes a forecast of the AUDUSD reaching $0.60 by the end of 2019, because the final models' forecasts are in terms of returns due to accounting for non-stationarity in levels, there is some ambiguity regarding whether the forecasts are exactly consistent because levels cannot be compared to returns (Cullinane, 2019). This is an important limitation of the forecasts. From the predictions and the current AUDUSD rate, it is unlikely that decreases of -0.004 to -0.008% per month will yield a result close to the economic research firm's forecasts by the end of 2019.

Section 5: Conclusions and Implications

The main purpose of this project was to predict long-term behaviour of exchange rates over the next year. From the analysis conducted, the level of exchange rate between Australia and four countries (AUDUSD, AUDNZD, AUDCAD, AUDCHF), the respective interest rate differentials between these countries and the Australian net exports were found to be non-stationary through unit root tests. This meant that the processes were not in statistical equilibrium and follow random walks, hence forecasting should use more sophisticated models (Appiah ST, 2011). Following that, the Johansen cointegration test was used to reveal whether a VECM model could be applied for any of the assumed cointegration relationships which consistent of an exchange rate being influenced by an interest rate differential and the Australian net exports. If the test failed to show evidence of any cointegration relationships, a VAR based on the integrated order level was used instead. Both models were used to investigate the claims made by firms in Section 1 and these models were used to make ex-ante forecasts.

The forecasts aligned with the firm claims as the analysis illustrated that all exchange rates are forecasted to decrease at a decreasing rate. This implies that the relative value of the Australian currency compared to the four other currencies may be lower moving into next year.

These results have key implications. If the forecasts are true, consumers from US, New Zealand, Canada and Switzerland will demand more of Australia's goods and services as their prices would be relatively lower to their domestic goods. This can also result to Australia importing less goods from those countries, leading to an increase in net exports and an improvement in the trade account. Australian universities which is a service export might also experience a boom in demand as such.

When setting the monetary policy, the RBA has a duty to contribute to the stability of the currency. Changing the interest rate could therefore be indirect intervention by the RBA to influence the exchange rates (Hamilton, 2018). If the forecasts are accurate, the RBA may increase the cash rate resulting in an increase in the interest rate of Australia relative to the rest of the world. If this occurs, returns on Australian assets can rise and demand for Australian dollars are likely to increase inducing an appreciation of the exchange rate. However, RBA will take those measures only if there is severe volatility in the exchange rate and the models do not account for future volatility of the exchange rate.

However, there are several limitations of the findings from this project:

1. The underlying cointegration relationships between the two VECM models were assumed to be true whereas the true cointegration relationship could be any combination of the variables. Further analysis and understanding of the economic theory underlying these variables may lead to better assumptions on the underlying cointegrating relationships. For example, the Diebold Yilmaz Spillover index could have been used to determine how an exchange rate is connected to interest rate differentials and Australian net exports. Granger causality tests and Impulse Response Analysis could have produced a richer analysis as well. However, none of the above could be done due to space constraints.

2. Since the Johansen test suggested VAR and VECM as the optimal models for the four exchange rates, it was decided not to test ex-post forecasts and root mean squared errors (RMSEs). This is because even though it is potentially possible to test a VAR alongside a VECM suggested by the cointegration test, it is incorrect to test a VECM alongside a VAR suggested by the cointegration test (if there are no cointegration relationships, cannot use VECM). Therefore, ex-post forecasts could technically be performed on the log(AUDNZD) and log(AUDCHF) VECM models but this would not be consistent with avoiding ex-post forecasts on the other two models. A solution would be to consider and test other models e.g. ARIMA but the focus was on the materials taught in the subject so far.

3. In general, from the time series plots in figures 1 and 3, the negative relationship between exchange rates and Australian net exports is inconsistent with theory. Potential reasons why may include:
   a) Although US and New Zealand are among the ten biggest trading partners of Australia, China and Japan which are the two biggest trading partners which were not accounted for in the analysis (Kimmorley, 2014).
   b) There might be other factors not accounted for in the analysis which may be driving the currencies down apart from net exports.

4. Finally, reiterating briefly from Section 4, forecasted returns in the project cannot fully be compared to the forecasted level made by Capital Economics, one of the main investigations of the project.

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