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Concurrent Session 100: Modeling Demand Response

Electricity demand elasticity in Mauritius: an ARDL bounds test approach to cointegration

Anna Genave
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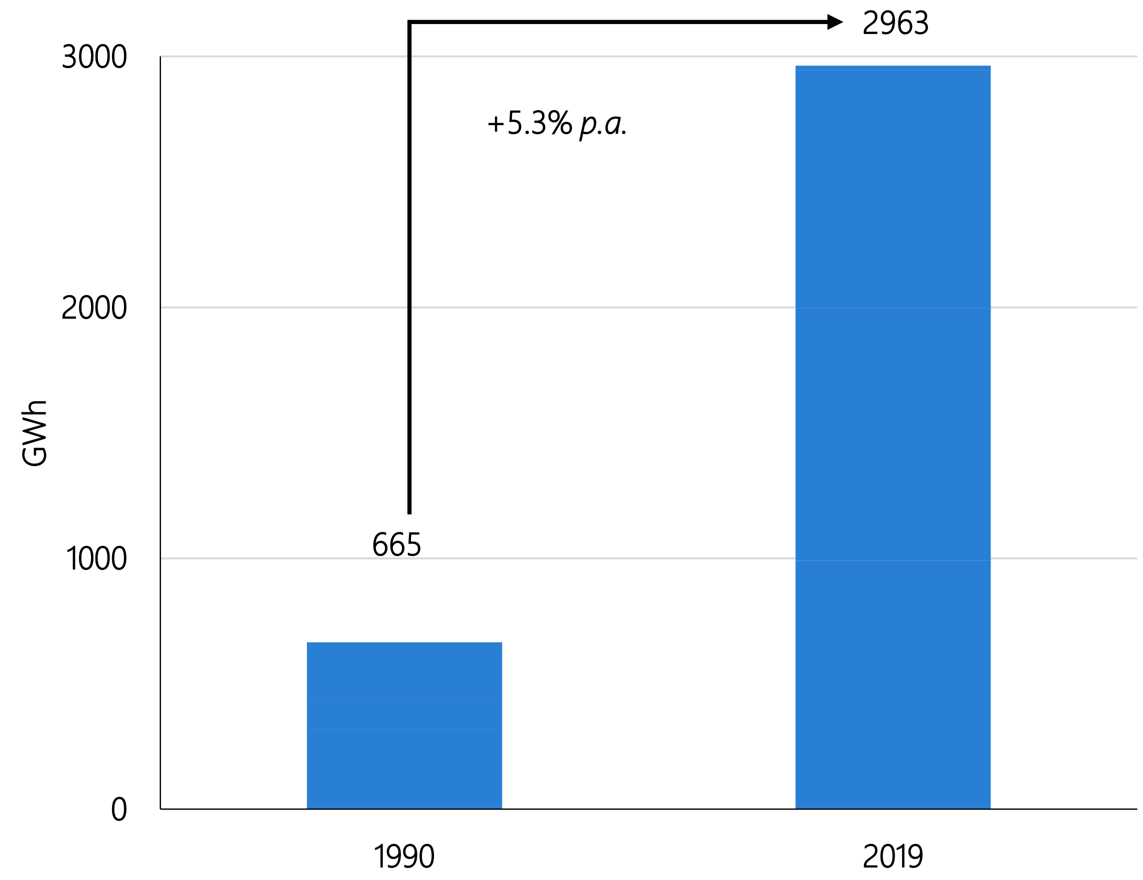
9 June 2021

1 Background

Aggregate electricity consumption

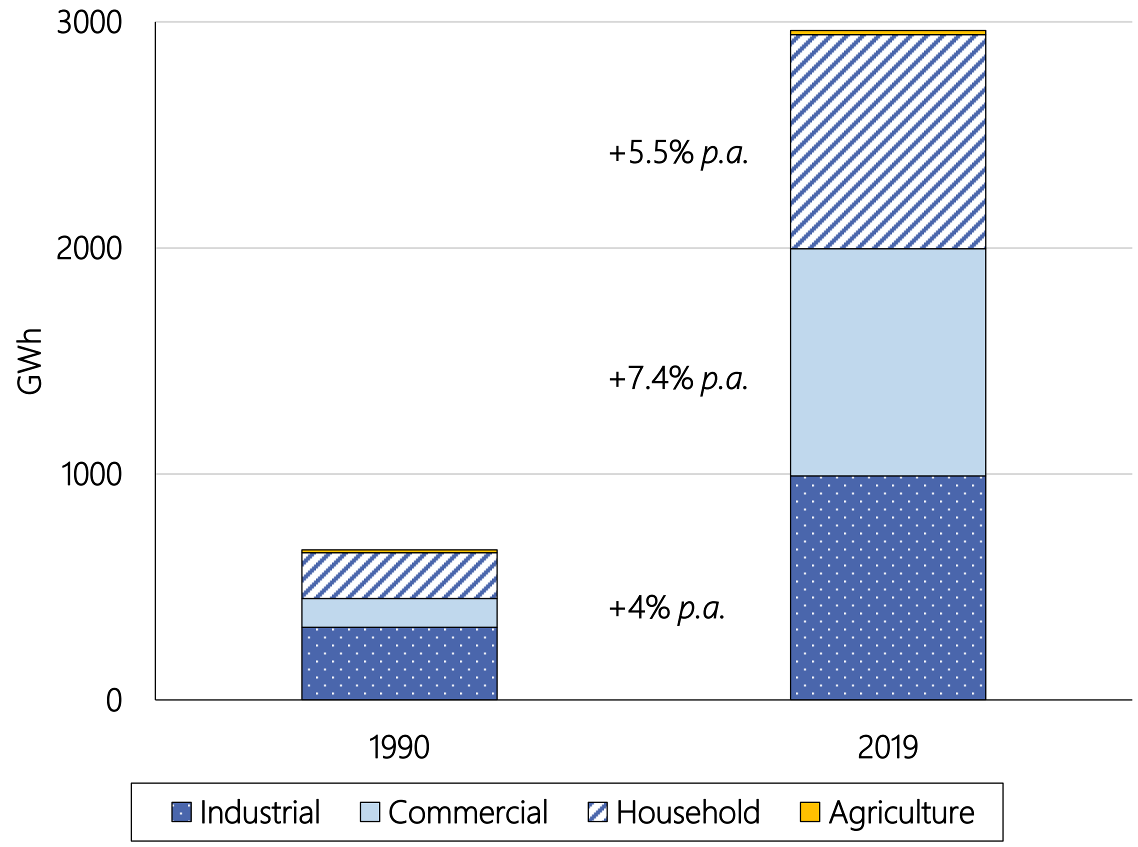
Figure 1 : Electricity demand (GWh) between 1990 and 2019



- Increase in electricity consumption at an AAGR of 5.3% *p.a.*
- Electricity consumption represents 25% of total final energy consumption

Electricity consumption by sector

Figure 2 : Electricity demand (GWh) between 1990 and 2019



- Increase in household electricity demand mainly due to higher income and living standards

- Increase in commercial electricity demand which is a service-oriented sector where electricity is the primary energy source.

- Slower growth rate in the industrial sector mainly due higher added-value production and adoption of more efficient processes

Research question

What are the main drivers of electricity consumption in Mauritius?

- What is the nature and magnitude of the relationship between electricity consumption and its drivers?
- Is there a long-run equilibrium path for electricity consumption?
- What are the policy implications?

2 Literature review

Selected studies estimating electricity consumption including at least one island

Type of studies	Authors	Countries	Variables	Methods	Main findings
Single-country	Sultan (2012)	Mauritius	GDP per cap Investment per cap Electricity consumption per cap Exports per cap	ARDL bounds test approach to cointegration + Johansen-Juselius test	Multiple causal relationships
	Narayan and Singh (2007)	Fiji	GDP Energy use Labour force	ARDL bounds test approach to cointegration	Unidirectional causality from electricity consumption to GDP
	Katircioglu (2013)	Singapore	Energy consumption Imports	ARDL bounds test approach to cointegration + Johansen Cointegration test	Unidirectional causality from energy to imports
Multi-country	Mishra et al. (2009)	9 Pacific Islands	Energy consumption per cap GDP per cap Urbanization	Panel Cointegration test + Granger causality test	Bidirectional causality between energy consumption and GDP
	Shabaz et al. (2014)	91 countries including 4 islands	Trade openness Electricity consumption	Panel Cointegration test + multiple causality tests	Bidirectional causality between trade and energy consumption
	Antonakakis et al. (2017)	106 countries including 7 islands	GDP per capita CO_2 emissions per cap Final energy consumption including electricity	Panel Granger causality test	Multiple Granger causal links for different income-based groups
	Wang et al. (2018)	170 countries including 30 islands	Urbanization CO_2 emissions GDP per cap Energy consumption per cap	Pedroni cointegration test for panel data + Panel Granger causality test	Multiple Granger causal links for different income-based groups

3 Methodology

Data

Annual data for the period 1978-2019

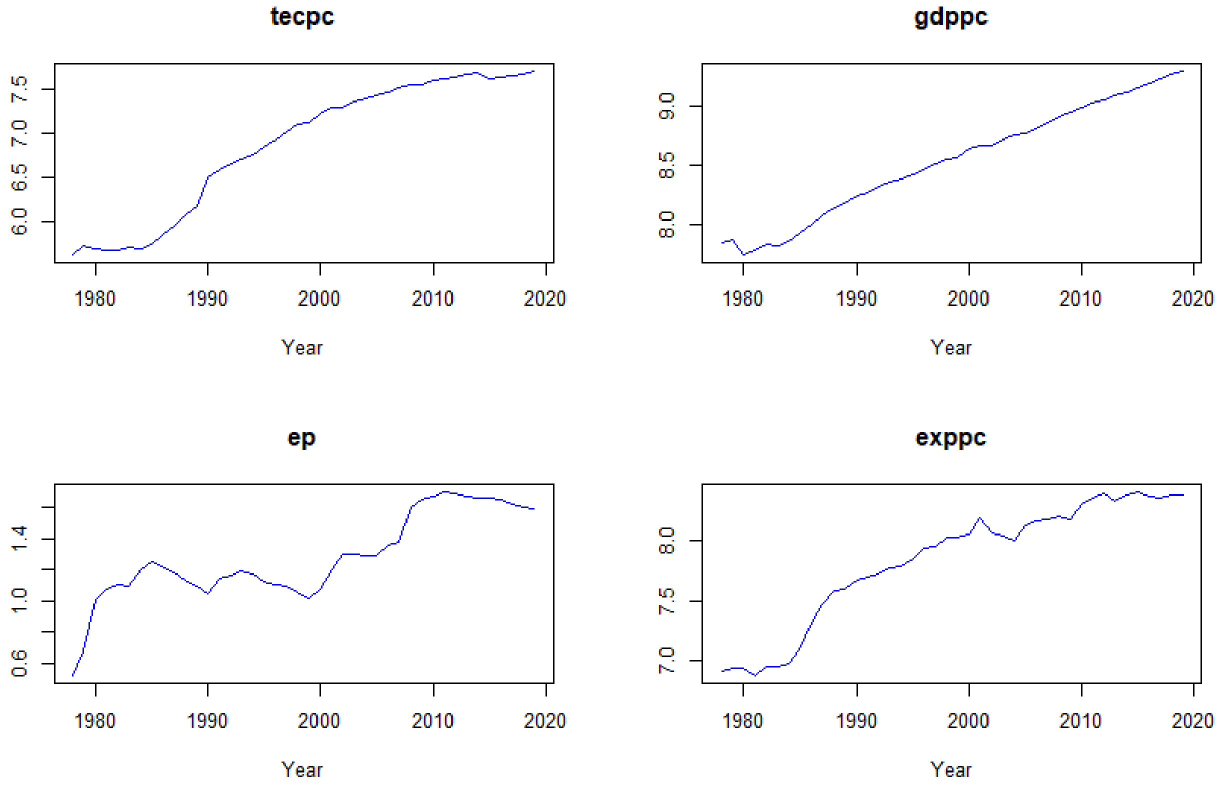
Dependent variable

- Electricity consumption per capita (**tecpc**)

Explanatory variables

- Real GDP per capita (**gdppc**)
- Average price of electricity (**ep**)
- Exports per capita (**exppc**)

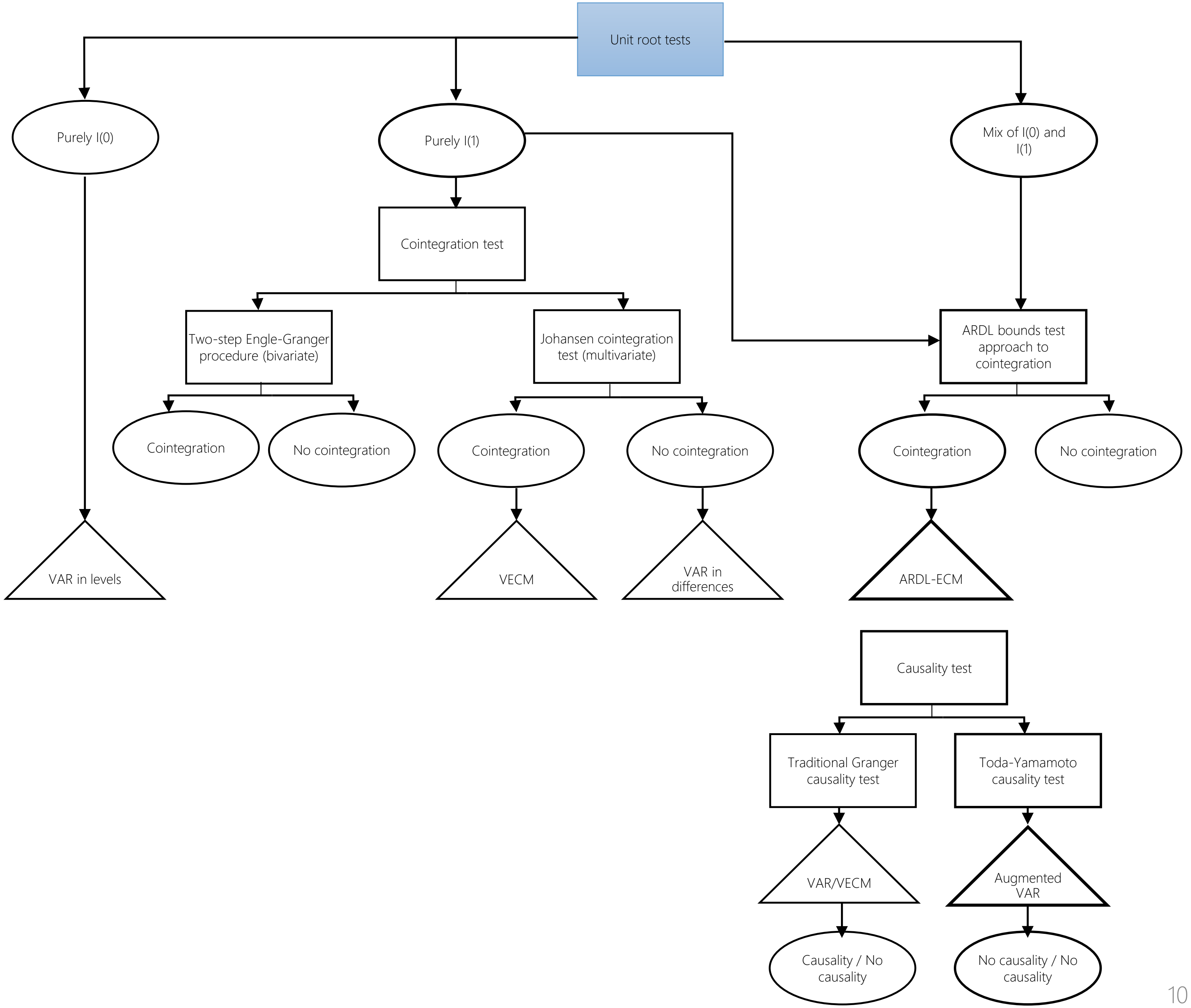
Figure 3: Time series of variables of interest in logarithm



Series potentially affected by a trend and cointegrated

Modeling strategy

Figure 4: Schematic representation of modeling choices



Unit root tests

Purely I(0)

Purely I(1)

Mix of I(0) and I(1)

Cointegration test

Two-step Engle-Granger procedure (bivariate)

Johansen cointegration test (multivariate)

ARDL bounds test approach to cointegration

Cointegration

No cointegration

Cointegration

No cointegration

Cointegration

No cointegration

VAR in levels

VECM

VAR in differences

ARDL-ECM

Causality test

Traditional Granger causality test

Toda-Yamamoto causality test

VAR/VECM

Augmented VAR

Causality / No causality

No causality / No causality

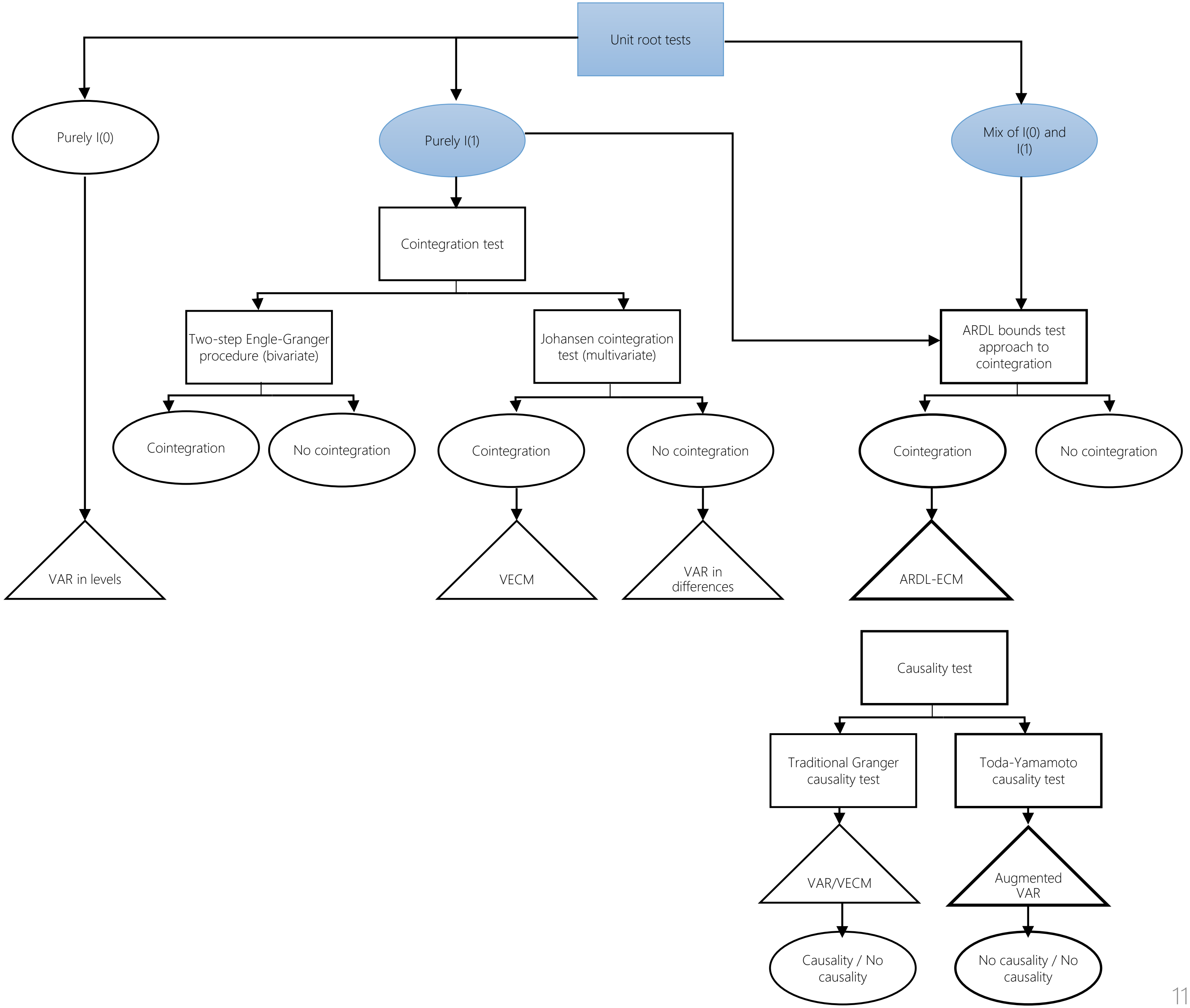
Legend

▭ Test to be performed

◯ Outcome

△ Model to be estimated

Modeling strategy



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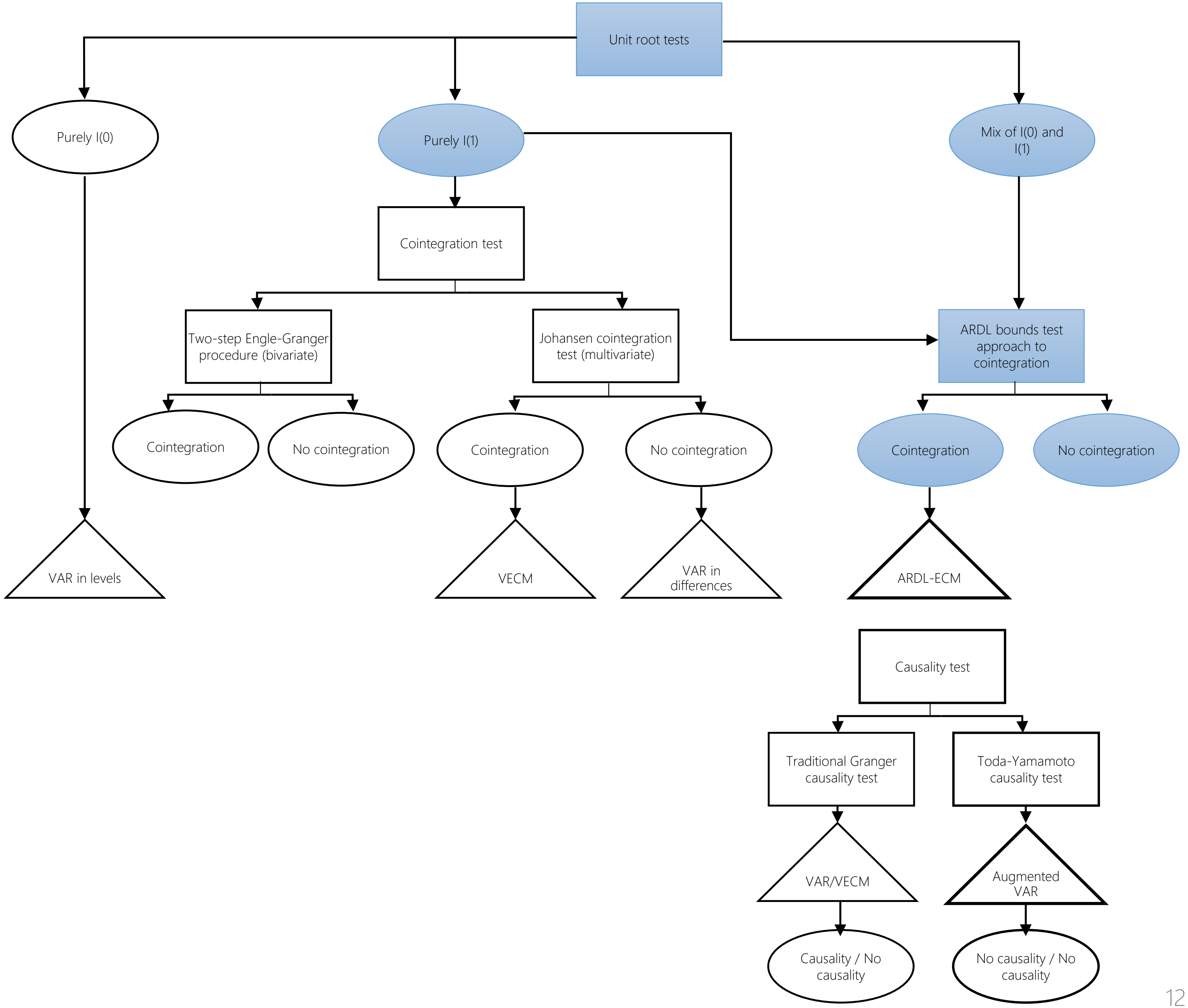

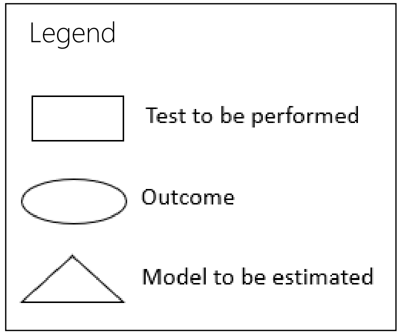

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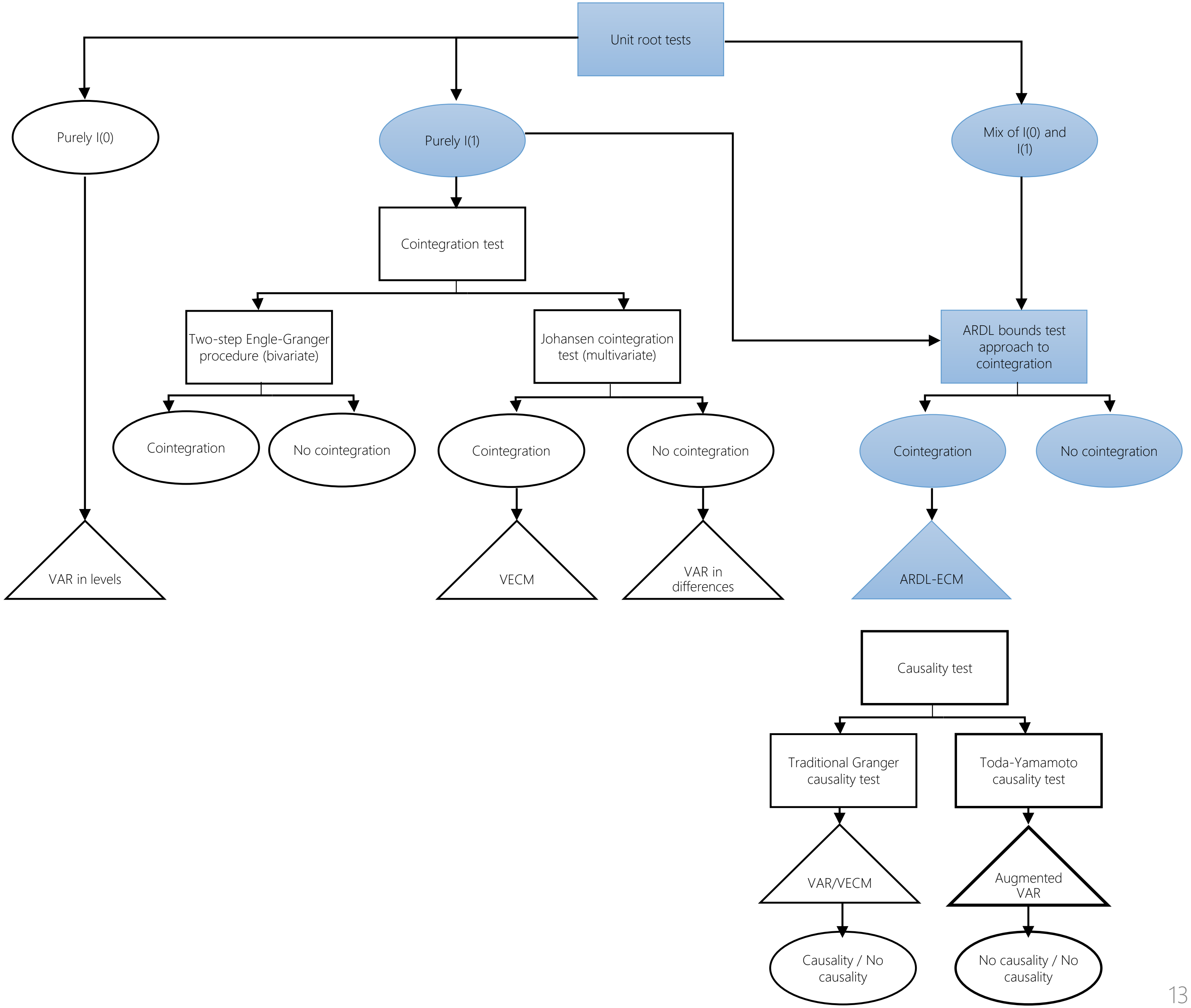

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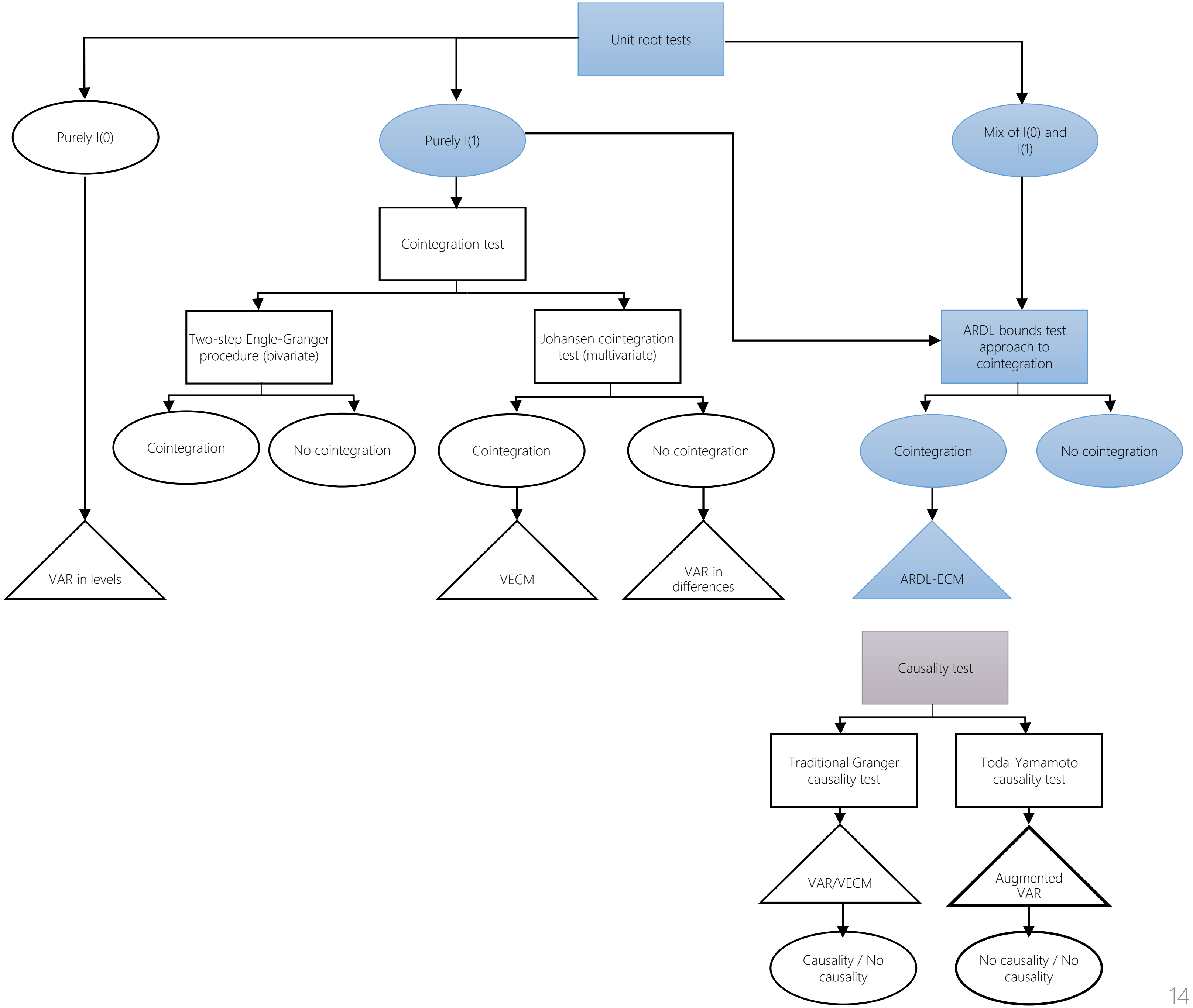

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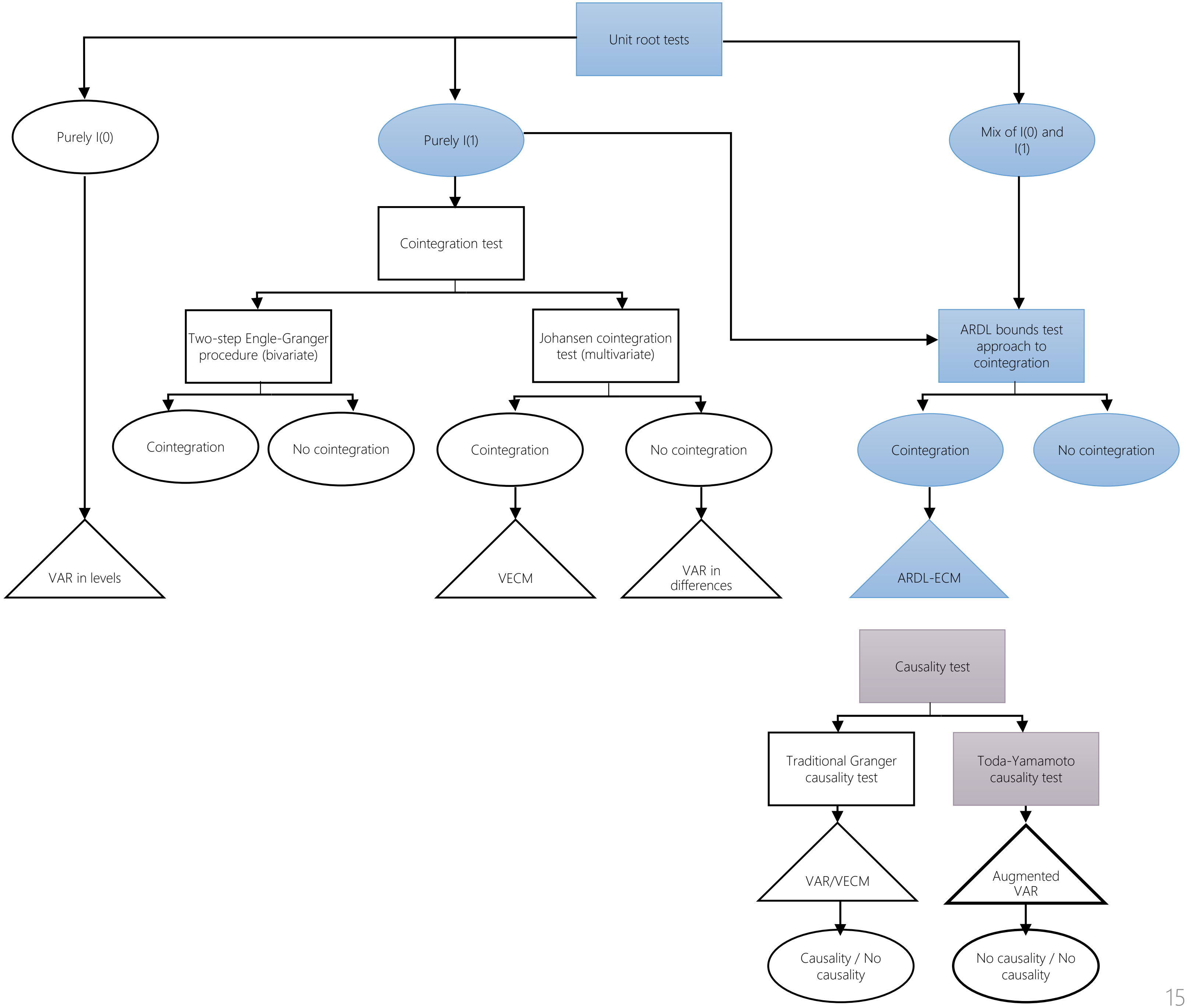

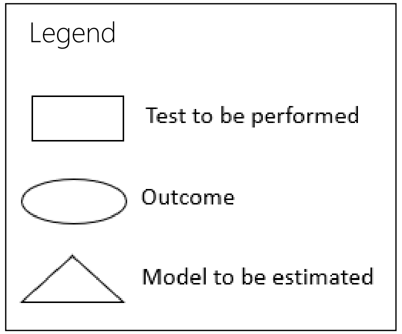

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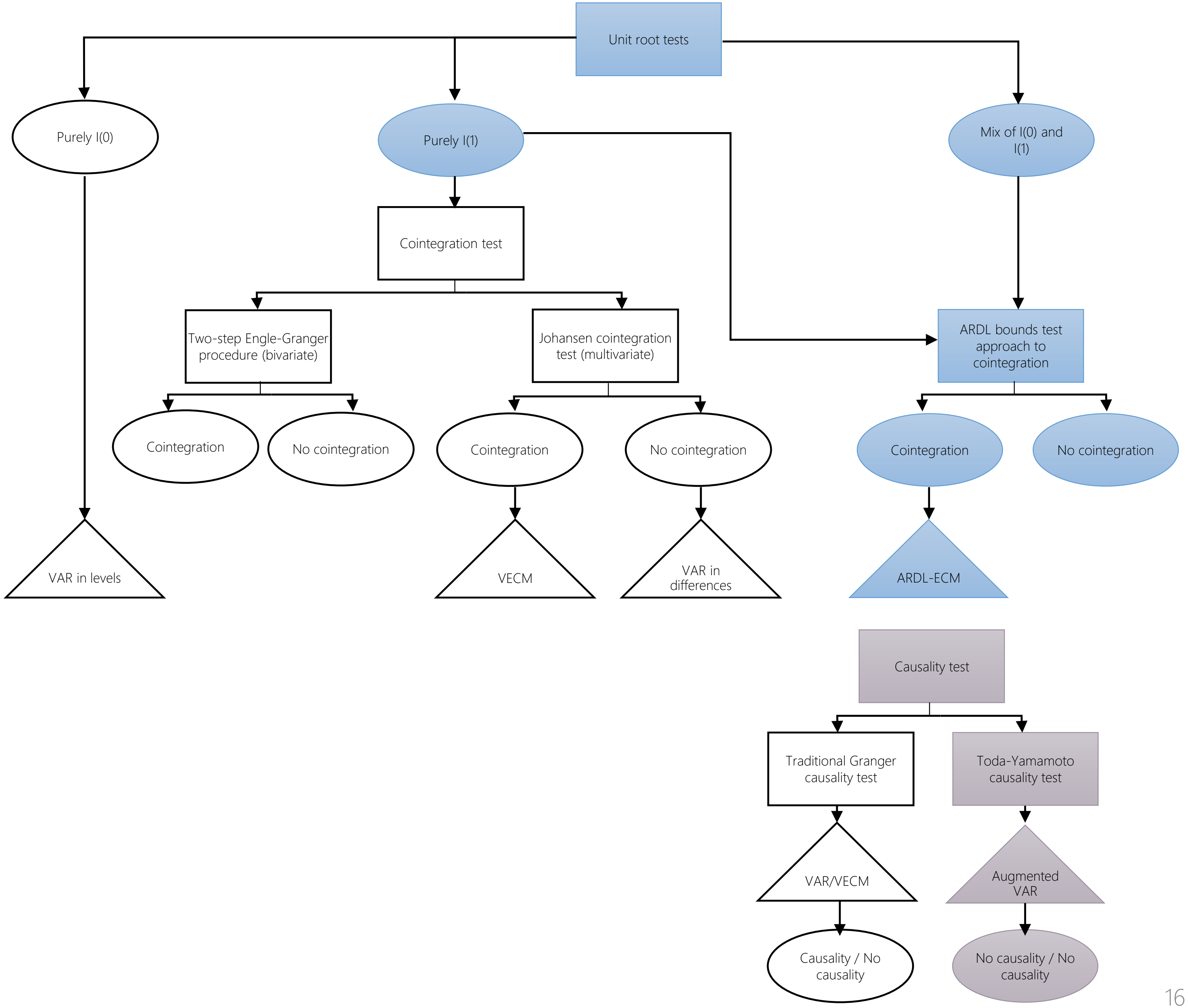

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Empirical setting: ARDL-ECM

Error correction term

$$\Delta tecpc_t = \sum_{i=1}^{q-1} \varphi_i \Delta tecpc_{t-i} + \sum_{j=1}^{p1-1} \beta_j \Delta gdppc_{t-j} + \sum_{j=1}^{p2-1} \gamma_j \Delta ep_{t-j} + \sum_{j=1}^{p3-1} \lambda_j \Delta exppc_{t-j} + \boldsymbol{\psi_{tecpc}} \boldsymbol{ECT_{t-1}} + \varepsilon_t \quad (1)$$

Adjustment parameter

$$\boldsymbol{ECT_{t-1}} = tecpc_{t-1} - \left(\frac{\alpha_0}{1 - \sum_{i=1}^{p} \varphi_i}\right) - \left(\frac{\sum_{j=0}^{q1} \beta_j}{1 - \sum_{i=1}^{p} \varphi_i}\right) gdppc_{t-1} - \left(\frac{\sum_{j=0}^{q2} \gamma_j}{1 - \sum_{i=1}^{p} \varphi_i}\right) ep_{t-1} - \left(\frac{\sum_{j=0}^{q3} \lambda_j}{1 - \sum_{i=1}^{p} \varphi_i}\right) exppc_{t-1} \quad (2)$$

Deviation of $\boldsymbol{tecpc_{t-1}}$ from its long-run equilibrium

Toda-Yamamoto causality test

k optimal lags

$$\begin{bmatrix} tecpc_t \\ gdppc_t \\ ep_t \\ exppc_t \end{bmatrix} = \begin{bmatrix} \eta_0 \\ \theta_0 \\ \omega_0 \\ \pi_0 \end{bmatrix} + \sum_{i=0}^{k} \begin{bmatrix} \eta_{1i} & \eta_{2i} & \eta_3 i & \eta_{4i} \\ \theta_{1i} & \theta_{2i} & \theta_{3i} & \theta_{4i} \\ \omega_{1i} & \omega_{2i} & \omega_{3i} & \omega_{4i} \\ \pi_{1i} & \pi_{2i} & \pi_{3i} & \pi_{4i} \end{bmatrix} \begin{bmatrix} tecpc_{t-i} \\ gdppc_{t-i} \\ ep_{t-i} \\ exppc_{t-i} \end{bmatrix} + \sum_{j=1}^{d_{max}} \begin{bmatrix} \kappa_{1j} & \kappa_{2j} & \kappa_{3j} & \kappa_{4j} \\ \zeta_{1j} & \zeta_{2j} & \zeta_{3j} & \zeta_{4j} \\ \tau_{1j} & \tau_{2j} & \tau_{3j} & \tau_{4j} \\ \phi_{1j} & \phi_{2j} & \phi_{3j} & \phi_{4j} \end{bmatrix} \begin{bmatrix} tecpc_{t-j} \\ gdppc_{t-j} \\ ep_{t-j} \\ exppc_{t-j} \end{bmatrix} + \begin{bmatrix} \epsilon_{1t} \\ \epsilon_{2t} \\ \epsilon_{3t} \\ \epsilon_{4t} \end{bmatrix} \tag{3}$$

If $\sum_{i=0}^{k} \eta_{2i} = \mathbf{0}$, then $\boldsymbol{gdppc_t}$ does not Granger-cause $\boldsymbol{tecpc_t}$

Inversely, if $\sum_{i=0}^{k} \theta_{1i} = \mathbf{0}$, then $\boldsymbol{tecpc_t}$ does not Granger-cause $\boldsymbol{gdppc_t}$

4 Results and discussion

Non-stationary series integrated of order 1

Table 1: Results of unit root tests

Variables	ADF			PP		KPSS	
	T&C	C	N	T&C	C	T&C	C
Levels							
tecpc	−0.644	−2.770	-	−0.146	−1.579	0.445***	2.079***
gdppc	−3.132	-	-	−3.517	0.439	0.107	2.159***
ep	−1.999	−1.044	0.721	−3.04	−2.704	0.137	1.201***
exppc	−2.520	−3.309**	-	−0.918	−1.680	0.432***	1.991***
First diff							
tecpc	−4.235***	-	-	−4.320**	-	0.176**	0.460
gdppc	−4.939***	-	-	−5.439***	-	0.124	0.141
ep	−3.419	−3.417	−3.407***	−3.980**	-	0.141	0.229
exppc	−4.428	-	-	−5.342***	-	0.066	0.302
CV							
5%	−3.50	−2.93	−1.95	−3.586	−2.974	0.146	0.463
1%	−4.15	−3.58	−2.62	−4.338	−3.695	0.216	0.739

*** , * denote statistical significance level at 1% and 5%

T&C: Trend and constant; C: Constant only; N: None (no trend and no constant); CV: Critical values

Unit root tests

- ADF (Dickey and Fuller, 1979; 1981)
- PP (Phillips and Perron, 1988)
- KPSS (Kwiatkowski et al., 1992)

Stationarity and order of integration

→ Non-stationary in levels

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Integrated non-stationary series of order 1 → I(1)

Non-stationary series integrated of order 1 and cointegrated

Table 2: Results of the ARDL bounds test approach to cointegration

Function	ARDL model	F-stat	*CV at* 5%		*CV at* 1%	
			I (0)	I (1)	I (0)	I (1)
$\mathrm{F_{tecpc}(tecpc\|gdppc, ep, exppc)}$	(1,0,0,0)	**12.038*****	3.5385	4.8204	5.0448	6.6253
$\mathrm{F_{gdppc}(gdppc\|tecpc, ep, exppc)}$	(3,1,0,0)	3.145	3.5974	4.8532	5.0547	6.6570
$\mathrm{F_{ep}(ep\|tecpc, gdppc, exppc)}$	(1,0,1,0)	2.3874	3.5385	4.8204	5.0448	6.6253
$\mathrm{F_{exppc}(exppc\|teppc, gdppc, ep)}$	(1,0,1,0)	1.3554	3.5385	4.8204	5.0448	6.6253

*** denotes statistical significance level at 1%

- Existence of a unique cointegrating relationship
- Explanatory variables are weakly exogenous
- Validation of the 'conditional' model

Cointegration test

- Pesaran and Shin (1995) and Pesaran et al. (2001)

$$\Delta tecpc_t = \alpha_0 + \sum_{i=1}^{p-1} \varphi_i \Delta tecpc_{t-i} + \sum_{j=1}^{q1-1} \beta_j \Delta gdppc_{t-j} + \sum_{j=1}^{q2-1} \gamma_j \Delta ep_{t-j} + \sum_{j=1}^{q3-1} \lambda_j \Delta exp_{t-j} + \delta_1 tecpc_{t-1} + \delta_2 gdppc_{t-1} + \delta_3 ep_{t-1} + \delta_4 exppc_{t-1} + \varepsilon_t \tag{4}$$

$$\begin{cases} H_0 : \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0 & \rightarrow No\ cointegration \\ H_1 : \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq 0 & \rightarrow Cointegration \end{cases}$$

Long-run equilibrium relationship

Estimating the ARDL-ECM model

Table 3: Short-run estimates

Conditional Error Correction Regression

Variable	Coefficient	Std. Error	t-Statistic	Prob.
c	-1.151637	0.358753	-3.210115	0.0028
ECT (-1)	-0.210640	0.045512	-4.628238	0.0000
gdppc	0.072662	0.088737	0.818852	0.4183
ep	-0.138045	0.051682	-2.671043	0.0113
exppc	0.280250	0.060655	4.620365	0.0000

Levels Equation
Case 3: Unrestricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
gdppc	0.344958	0.272261	1.267013	0.2133
ep	-0.655357	0.209440	-3.129098	0.0035
exppc	1.330465	0.234199	5.680910	0.0000

ECT = tecpc - (0.3450*gdppc - 0.6554*ep + 1.3305*exppc)

- tecpc explained by its average price and exports
- Inelastic nature of tecpc to changes in price and exports
- Negative and highly significant adjustment parameter
- Deviations from the equilibrium path corrected up to 21%.

Estimating the ARDL-ECM model

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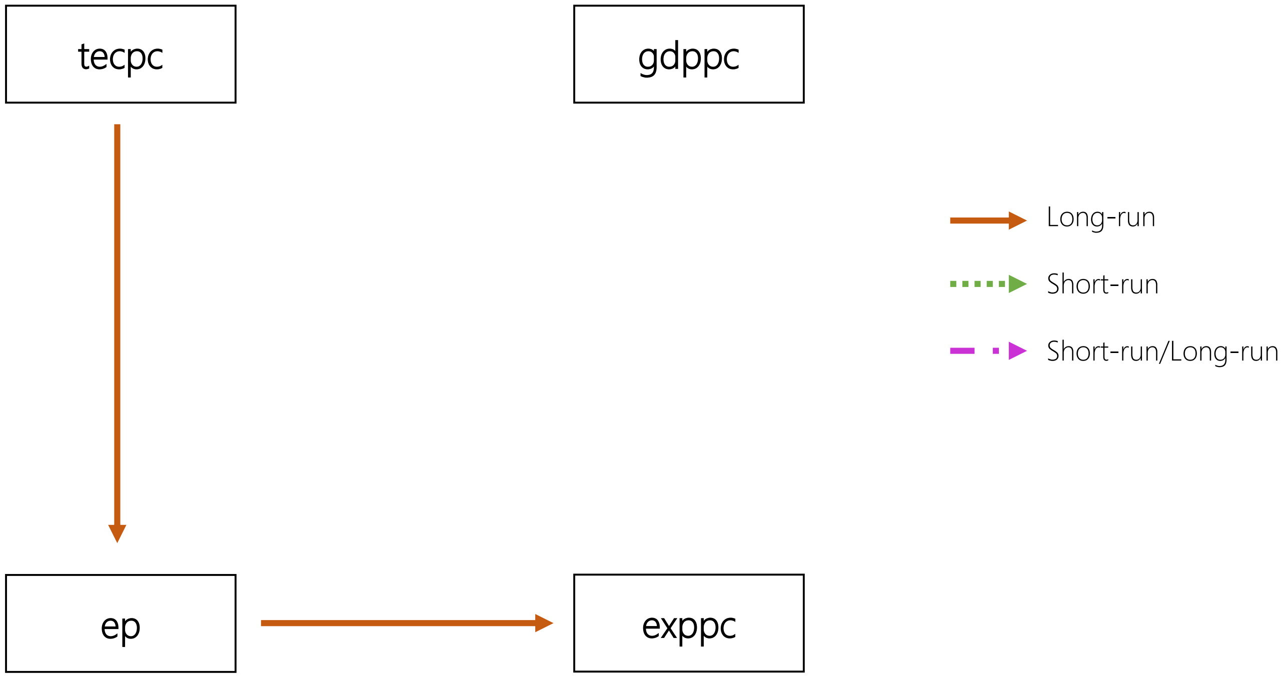
ECT = tecpc - (0.3450*gdppc - 0.6554*ep + 1.3305*exppc)

- gdppc still not significant
- Long-term drivers: electricity prices and exports per cap
- Inelastic nature of the electricity price effect: cross-subsidization
- tecpc becomes elastic to changes in exppc: increased output resulting in increased demand → structural transition of the economy

Toda-Yamamoto causality results

Figure 5: Direction of causality



tecpc

gdppc

ep

exppc

Long-run

Short-run

Short-run/Long-run

Current study

Electricity conservation policies do not hinder economic growth in Mauritius.

Toda-Yamamoto causality results

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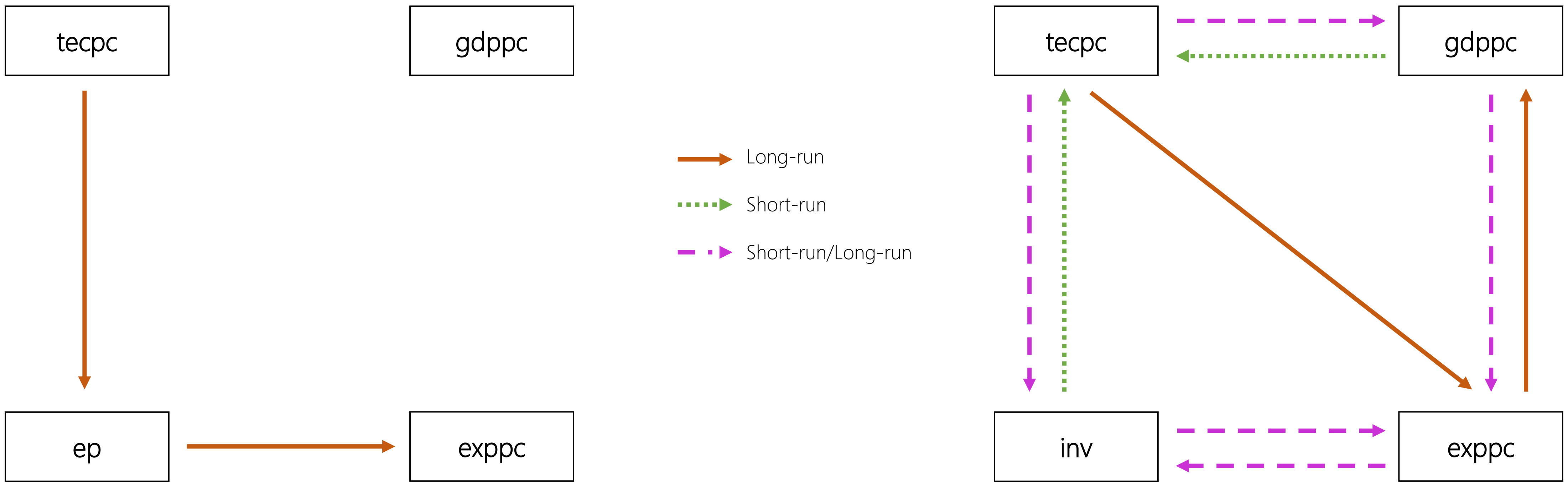

tecpc

gdppc

ep

exppc

Long-run

Short-run

Short-run/Long-run

tecpc

gdppc

inv

exppc

Current study

Sultan (2012)

Electricity conservation policies do not hinder economic growth in Mauritius.

Electricity conservation policies are detrimental to economic growth in Mauritius.

5 Concluding remarks

Main findings

1. Existence of a unique and stable cointegrating relationship.
2. Error-correcting mechanism → convergence towards long-run equilibrium path
3. Price inelasticity both in the SR and LR → prices are cross-subsidized and not cost-reflective
4. Absence of causality running from explanatory variables → implementation of energy-saving policies

Limitations and way forward

Limitations:

- Few observations → issues with data availability
- Results might be more nuanced when one considers sectoral electricity consumption

Future research outlets:

- Sectoral analysis of electricity consumption
- Long-term electricity demand projections → Demand scenarios for the prospective modeling of the power system of Mauritius

1st IAEE Online Conference
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Thank you!

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Appendices

Preliminary tests

Unit root tests

- ADF (Dickey and Fuller, 1979; 1981)
- PP (Phillips and Perron, 1988)
- KPSS (Kwiatkowski et al., 1992)

Stationarity and order of integration

Cointegration test

- Pesaran and Shin (1995) and Pesaran et al. (2001)

$$\Delta tecpc_t = \alpha_0 + \sum_{i=1}^{p-1} \varphi_i \Delta tecpc_{t-i} + \sum_{j=1}^{q1-1} \beta_j \Delta gdppc_{t-j} + \sum_{j=1}^{q2-1} \gamma_j \Delta ep_{t-j} + \sum_{j=1}^{q3-1} \lambda_j \Delta exppc_{t-j} + \delta_1 tecpc_{t-1} + \delta_2 gdppc_{t-1} + \delta_3 ep_{t-1} + \delta_4 exppc_{t-1} + \varepsilon_t \quad (1)$$

$$\begin{cases} H_0 : \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0 & \rightarrow No\ cointegration \\ H_1 : \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq 0 & \rightarrow \quad Cointegration \end{cases}$$

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$$\Delta tecpc_t = \alpha_0 + \sum_{i=1}^{p-1} \varphi_i \Delta tecpc_{t-i} + \sum_{j=1}^{q1-1} \beta_j \Delta gdppc_{t-j} + \sum_{j=1}^{q2-1} \gamma_j \Delta ep_{t-j} + \sum_{j=1}^{q3-1} \lambda_j \Delta exppc_{t-j} + \delta_1 tecpc_{t-1} + \delta_2 gdppc_{t-1} + \delta_3 ep_{t-1} + \delta_4 exppc_{t-1} + \varepsilon_t \quad (1)$$

Long-run equilibrium relationship

$$\begin{cases} H_0 : \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0 \rightarrow No\ cointegration \\ H_1 : \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq 0 \rightarrow Cointegration \end{cases}$$

ARDL-ECM (Conditional and marginal ECM)

Conditional model

$$\Delta tecpc_t = \sum_{i=1}^{q-1} \varphi_i \Delta tecpc_{t-i} + \sum_{j=1}^{p1-1} \beta_j \Delta gdppc_{t-j} + \sum_{j=1}^{p2-1} \gamma_j \Delta ep_{t-j} + \sum_{j=1}^{p3-1} \lambda_j \Delta exppc_{t-j} + \boldsymbol{\psi}_{\boldsymbol{tecpc}} ECT_{t-1} + \varepsilon_{1t}$$

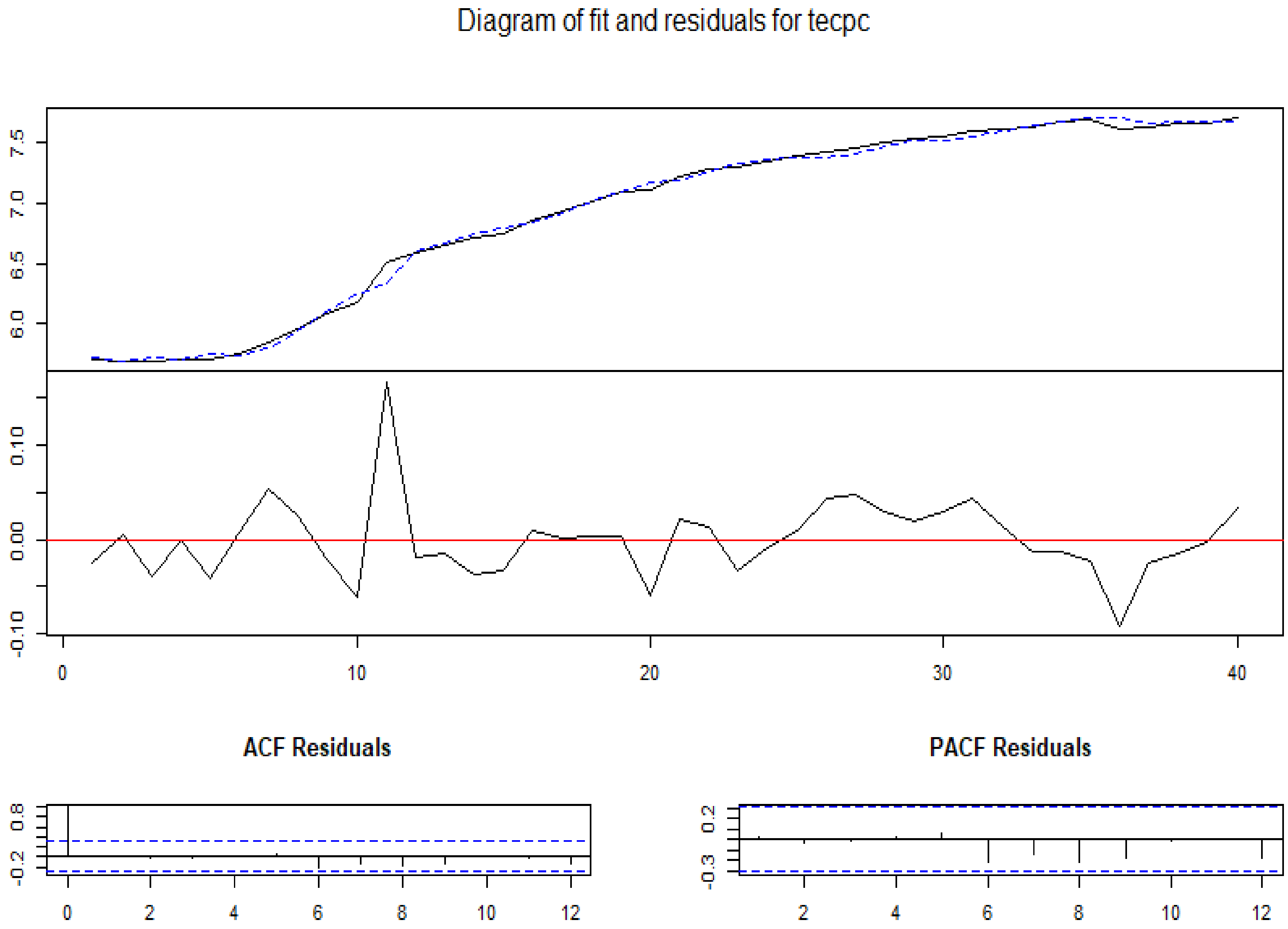
Marginal models

$$\Delta gdppc_t = \sum_{i=1}^{q-1} \beta_i \Delta gdppc_{t-i} + \sum_{j=1}^{p1-1} \varphi_j \Delta tecpc_{t-j} + \sum_{j=1}^{p2-1} \gamma_j \Delta ep_{t-j} + \sum_{j=1}^{p3-1} \lambda_j \Delta exppc_{t-j} + \boldsymbol{\psi}_{\boldsymbol{gdppc}} ECT_{t-1} + \varepsilon_{2t}$$

$$\Delta ep_t = \sum_{i=1}^{q-1} \varphi_i \Delta ep_{t-i} + \sum_{j=1}^{p1-1} \varphi_j \Delta tecpc_{t-j} + \sum_{j=1}^{p2-1} \beta_j \Delta gdppc_{t-j} + \sum_{j=1}^{p3-1} \lambda_j \Delta exppc_{t-j} + \boldsymbol{\psi}_{\boldsymbol{ep}} ECT_{t-1} + \varepsilon_{3t}$$

$$\Delta exppc_t = \sum_{i=1}^{q-1} \lambda_i \Delta exppc_{t-i} + \sum_{j=1}^{p1-1} \varphi_j \Delta tecpc_{t-j} + \sum_{j=1}^{p2-1} \beta_j \Delta gdppc_{t-j} + \sum_{j=1}^{p3-1} \gamma_j \Delta ep_{t-j} + \boldsymbol{\psi}_{\boldsymbol{exppc}} ECT_{t-1} + \varepsilon_{4t}$$

Model fit for conditional model



Model validation

Table 4: Residual and parameter tests

Diagnostic tests	
Specification (Ramsey RESET test)	3.193 [0.054]
Unit root test (ADF test)	-4.450 $[7.6e-05]^{***}$
Serial correlation (Breusch-Godfrey LM test)	0.008 [0.929]
Heteroscedasticity (Breusch-Pagan)	4.739 [0.315]
Normality (Shapiro Wilk test)	0.816 $[1.203e-05]^{***}$
Stability (Recursive CUSUM test)	0.732 [0.208]

Figure: Overall stability of the model parameters