# Is there any long run Granger-causality between economic growth and energy consumption ? evidence from Singapore

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# Is there any long run Granger-causality between economic growth and energy consumption ? evidence from Singapore

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## Abstract

The energy consumption and economic growth nexus has been an issue in energy economics in recent decades. Rapid technological advancement and the corresponding increase in energy demand compels countries worldwide to assess the defining crux between energy consumption and economic development prior to implementing socio-economic policies that may deter economic growth in the long-run. In an era of global warming, this is especially vital to countries implementing energy policies aimed at reducing the lingering effects of climate change. One such country is Singapore. A forerunning Asian Tiger, Singapore's concerted efforts to monitor its commitment to reducing carbon emissions has the urban city-state in a position where it must understand the energy consumption and economic growth nexus before it can devise energy policies focused on preserving the global climate, while simultaneously ensuring its concerted efforts toward long-run stable economic growth remains unhindered. The purpose of this study is to evaluate the energy consumption and economic growth nexus in Singapore. The methodology of this study employs the Autoregressive Distributed Lag (ARDL) approach to cointegration as proposed by Pesaran et al. (2001), and extends existing literature via the application of this cointegrating approach as it is previously unused in similar case studies. Findings indicate that no long-run causality exist between economic growth and energy consumption in Singapore, therefore denoting the presence of a neutrality hypothesis in the country's economy. This implies that Singapore's government would not experience negative economic growth as a result of its targeted policies towards reducing energy consumption in the country, further enhancing its position as a member of the Doha Amendment to the Kyoto Protocol.

**Keywords**: Granger-causality, Economic Growth, Energy Consumption, ARDL, Singapore

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## Introduction

Energy consumption has been a popular subject of socio-economic attention ever since the 1997 introduction of the Kyoto Protocol – a UN-led bid to reduce carbon emissions globally – and while the treaty's implementation did not come into effect prior to February 2005, signatories worldwide had already begun preliminary efforts into monitoring compliancy, and ultimately the engagement of domestic energy policies that would guarantee a ratified country's energy consumption levels fell in line with the Protocol's framework. Despite these efforts, economies worldwide could not ignore the importance between a country's stable economic growth and its domestic energy consumption levels. It was also understood that while a ratified country retained obligations towards the Protocol, it could not curb energy consumption at the cost of its own economic growth. As a result, it seemed vital that countries engaged in the treaty expanded efforts into studying the nexus between energy consumption and economic growth so as to better direct policies into realizing an optimum level between a country's domestic energy consumption needs in sustain long-term economic growth, and its designs towards the Protocol's framework.

As these past few decades have seen booming technological development, trade expansion, and rapid population growth lead to an increasing demand for energy consumption around the world, it is easy to assume that the economic growth that follows holds significant if not strong influences on the rate of energy consumption.

Nevertheless, literature on the subject of economic growth and energy consumption revealed four possible outcomes of this nexus. The first view, *feedback hypothesis*, supported by Masih and Masih (1996) implied bidirectional Granger causality between energy consumption and economic growth; while the second view, *growth hypothesis*, identified by Lee (2005), supported the argument that energy consumption Granger causes economic growth. Similarly, the third view, *conservation hypothesis*, supported by Cheng (1999), stated that economic growth Granger causes energy consumption; while another study, Cheng (1995), highlighted the presence of a fourth view, the *neutrality hypothesis*, where no causality was found between energy consumption and economic growth. That being said, Ozturk and Al-Mulali (2015) argued that of 83 studies led into the above research, only 52% indicated the existence of a feedback effect, while 28% supported the growth hypothesis, and another 10%

showed presence of the conservation hypothesis. Interestingly enough, the remaining 10% indicated the presence of neutrality hypothesis.

As a ratified member of the Doha Amendment to the Kyoto Protocol, Singapore became the 14th ratified country in 2014, and while the amendment still requires ratification from a further 129 countries before it can come into effect, Singapore had already begun efforts to reduce carbon emissions and energy consumption long before its ratification, through a series of energy policies introduced during the years 2007 to 2013.

The case of Singapore is an interesting premise due to its highly-urbanised city-state nature and scarcity of natural resources, however it has undoubtedly achieved rapid economic development since the 1990's, earning its position as a forerunning Asian Tiger economy. To date, Singapore has surpassed its surrounding nations, even that of its Asian Tiger members in terms of GDP per capita. Its position as the world's third leading hub for finance, being the only Asian country with a AAA sovereign credit rating, attracts a vast amount of foreign investment, most of which are channelled into its exceedingly advanced infrastructure and resounding economy. Known for its rank as the second freest economy in the world, Singapore benefits from numerous free-trade agreements and vast economic growth through its market freedom. Despite this, the Singaporean government retain significant stake in its operations regarding the economy via its lauded 'Singaporean Model'.

It is because of the Singapore government's close involvement with its economy that it ensures its policies do not hinder the country's economic growth upon implementation, and as a dynamic participant of multilateral negotiations under the UN Framework Convention on Climate Change (UNFCC), and its previously mentioned Kyoto Protocol, Singapore has since looked into numerous energy conservation polices as part of its National Energy Policy Framework to articulate comprehensive responses to climate change.[3] In 2006, the Singaporean government began its foray into adopting energy policies via the formulation of its Energy Policy Group, built to formulate and coordinate the country's energy policies and strategies. To date Singapore's energy conservations have been mandated through the

[3] The framework, released in 2007 comprises of 6 strategies encompassing Singapore's market sector, energy supply, imagery efficiency, energy R&D, international cooperation, and government intervention.

country's adoption of the Energy Conservation Act of 2012[4], where mandatory energy management practices are levied upon every registered corporation in Singapore, and by extension households.

From an economic perspective, Singapore's venture into reducing its energy consumption via policies may impact its prolific and sustained economic growth in the foreseeable future, especially when considering the general assumption that energy consumption has played a considerable role in economic growth so thus far. Therefore, it is imperative to explore the nexus between economic growth and energy consumption in Singapore so as to better identify the likely effects of such energy conservation policies. Through these empirical efforts the government of Singapore may seek to understand the causal relationship between economic growth and energy consumption in its country, and likely design policies that would allow the nation to maintain its long-term economic growth stability and meet its goals to reduce energy consumption levels.

The purpose of this study is to evaluate the energy consumption and economic growth nexus in Singapore. It employs the method of Autoregressive Distributed Lag (ARDL) approach previously not attempted by prior literature exploring the topic. In addition, the analysis of this paper is based on the empirical investigation of the causal relationship between energy consumption and economic growth in Singapore the aim is to investigate the long-run causal relationship between economic growth and energy consumption with particular reference to the Singaporean economy.

## Literature review

Over the years many investigations into the energy consumption and economic growth nexus have been attempted, all to varying degrees and with regards to varying countries or group of countries, as this relationship has been considered an imperative issue in energy economics Chiou-Wei (2008).

[4] The revised Energy Conservation Act (Chapter 92C), 2014 edition can be viewed at: http://statutes.agc.gov.sg/

The first attempt into understanding the economic growth and energy consumption nexus was by Kraft and Kraft (1978) where the authors confirmed the presence of unidirectional causality running from economic growth to energy consumption. The research had employed the methods of Granger causality and spanned a time series period of 27 years from 1947 to 1974 in the United States. Another oft-cited literature exploring the energy consumption and economic growth nexus was Masih and Masih (1996), where the authors illustrated the existence of causality between energy consumption and income. Their researched implied that an energy-dependant country may experience negative externalities in the form of reduced income during periods of energy shortages. However, as the recent decades vast literature on the economic growth and energy consumption nexus expands, Lee (2005) noted that while the relationship between energy consumption and income has become a popular area of empirical research in economics, to date, causality is still expected to run in either direction as there is a lacking consensus regarding the permanency as well as transitionality of the relationship.

**Bidirectional causality and the ARDL approach**

Fuinhas and Marques (2012) illustrated bidirectional causality between energy consumption and economic growth in both the long-run and short-run of five European economies: Portugal, Italy, Greece, Spain, and Turkey. The research also supported the feedback hypothesis where energy conservation policies were likely to reduce GDP growth.

**Unidirectional causality and the ARDL approach**

A prima-facie casual flow from electricity consumption to economic growth was detected in Odhiambo (2009), where causality tests using the ARDL approach found unidirectional causal flow from total energy consumption in Tanzania to its economic growth. Subsequently, Odhiambo (2010), illustrated the presence of unidirectional causal flow from energy consumption to economic growth for both South Africa and Kenya, but a reverse unidirectional casual flow in Congo, where economic growth led energy consumption. Interestingly, Odhiambo is one of the few literatures on the subject of economic growth and energy consumption to use the ARDL bounds testing approach in determining causality. Khandelwal (2015) led a similar ARDL bounds testing approach in addition to VECM when examining the impact of energy consumption, GDP, and fiscal deficit on health expenditure in

India. The study's outcome reveal long-run causal relationship between energy consumption and GDP, and implied that India's efforts to improve its fiscal situation should in part be targeted at reducing energy imports. Finally, Kumar, Stauverman and Kumar (2014) argued the presence of unidirectional causality from output per worker to energy consumption per worker in Albania, Bulgaria, Hungary, and Romania via the ARDL bounds testing approach. The study concluded that a balance between sound energy conservation policies and effective energy consumption were needed to support stable economic growth in these countries.

**Unidirectional causality and other approaches**

A panel study investigation by Lee (2005) refuted the neutrality hypothesis, indicating that developing countries with long-run unidirectional causal relationship from energy consumption to GDP but not vice versa were at risk of harming future economic growth. The author argued that regardless of permanent or transitory nature developing countries sustained an energy-income relationship that supported a unidirectional causal relationship from energy to consumption where high energy consumption tended to lead to high economic growth.

**Economic growth and energy consumption nexus in Singapore**

In a multi-country study by Masih and Masih (1996) the relationship between energy consumption, real income, and temporal causality for various countries was examined via the use of error correction modelling techniques (or VECM). Of the countries investigated, Singapore was an area of interest, and in the 1996 research, the authors concluded that the long-term equilibrium relationship between energy consumption and economic growth was not found in Singapore, therefore supporting the neutrality hypothesis. Consequently, Glasure and Lee (1998) once again explored the causality between GDP and energy in Singapore via similar techniques to Masih and Masih (1996). The authors results indicated Granger unidirectional causality from energy consumption to GDP for Singapore, and this spurred further research into the subject as interest for the issue developed. A most recent study by Chiou-Wei (2008) attempted to broaden the exploration of this nexus by employing linear and non-linear Granger causality methods in examining Singapore's relationship between energy consumption and economic growth. The authors found empirical evidence revealing that Singapore possessed nonlinear unidirectional causality running from economic growth to energy consumption, possibly owed to structural breaks such as the Asian Financial Crisis or the oil crisis. The results

of Chiou-Wei (2008) argued that in terms of policy implementations, Singapore's unidirectional causality meant that the country's efforts to mitigate global warming regarding the Kyoto Protocol, and its implementation of energy conservation policies would not significantly impact Singapore's economic growth.

**Data and Model Specification**

With reference to empirical literature, the standard log-linear functional form specification of long-run relationship between energy consumption, real GDP, and fixed capital formation as a proxy can be expressed as:

$$ENG_t = \alpha + \beta_2 GDP_t + \beta_3 FC_t + \varepsilon_t$$

Where:

$$ENG_t = energy\ use\ (kg\ of\ oil\ equivalent\ per\ capita)$$
$$GDP_t = real\ GDP\ per\ capita\ (constant\ 2005\ US\$)$$
$$FC_t = Gross\ Fixed\ Capital\ Formation\ (proxy\ for\ GDP\ growth)$$[5]

Following this, the model for this study can be expressed as:

$$LENG \sim \alpha + \beta_1 LGDP + \beta_2 LFC + \varepsilon_t$$

Where:

$$LENG = Energy\ Consumption\ in\ Singapore$$
$$LGDP = Gross\ Domestic\ Product\ in\ Singapore$$
$$LFC = Gross\ Fixed\ Capital\ Formation\ in\ Singapore\ (proxy\ for\ GDP\ growth)$$
$$\varepsilon_t = error\ term$$

The above is an expression of the model in the vector error correction model, albeit this study following the ARDL approach. Furthermore, we have refrained from including the equality sign at this initial stage.

The time series data used in this study is obtained from World Development Indicators (WDI), comprising of annual data for Singapore, covering a period of 39 years starting from 1975. Data to represent economic growth is GDP per capita (constant 2005 US$), while energy

[5] As used in a similar study by Lee (2005)

consumption is represented by energy use (kg of oil equivalent per capita), and the added proxy for GDP is Gross Fixed Capital Formation (constant 2005 US$). All variables are in natural log form and have been differenced once.

The initial equation for this paper is expressed in the following ARDL from:

$$\Delta ENG_t = \alpha + \sum_{i=1}^{k} \emptyset_i \, \Delta ENG_{t-i} + \sum_{j=0}^{l} \beta_j \Delta GDP_{t-j} + \sum_{k=0}^{m} \beta_k \Delta FC_{t-k} + \delta_1 ENG_{t-1} + \delta_2 GDP_{t-1} + \delta_3 FC_{t-1} + v_t$$

Where:

$$v_t = white\ noise\ term$$

$$\Delta = first\ difference\ operator$$

Following this, should there be presence of cointegration between the variables, that long-run model may be expressed like this:

$$ENG_t = \alpha + \sum_{i=1}^{k} \emptyset_i \, \Delta ENG_{t-i} + \sum_{j=0}^{l} \beta_j \Delta GDP_{t-j} + \sum_{k=0}^{m} \beta_k \Delta FC_{t-k} + \mu_t$$

And the short-run model may be expressed as follows:

$$\Delta ENG_t = \alpha + \sum_{i=1}^{k} \emptyset_i \, \Delta ENG_{t-i} + \sum_{j=0}^{l} \beta_j \Delta GDP_{t-j} + \sum_{k=0}^{m} \beta_k \Delta FC_{t-k} + \varphi ECT_{t-1} + \omega_t$$

Where:

$$\varphi = the\ coefficient\ of\ the\ error\ term\ (ECT)$$

The ECT will illustrate how quickly variables converge toward the equilibrium, and it is expected to have a negative sign as well as a statistically significant coefficient. Ozturk (2010).

**Methodology and Analysis**

This study examines the energy consumption and economic growth nexus in Singapore by applying the Auto Regressive Distributed Lag (ARDL) model developed by Pesaran, Shin and Smith (2001), by using the previously mentioned variables, GDP, energy consumption, and proxy capital formation in line with previous studies conducted on the same issue as well as our research objective. The ARDL bounds test is used to test the presence of long-run causal relationship on the lagged levels of our variables. The cointegrating approach is used to identify endogenous variables (dependant) and exogenous variables (independent), and is considered ideal for small data samples and bivariate equations, although we will be using the addition of the proxy variable fixed capital formation to strengthen our results. Similar to traditional cointegration approaches, the ARDL also provides us with an error correction model equation for each variable which will be analysed in further detail later in this paper.

We began our empirical research by determining the stationary of each variable used in the time series, so as to enable us to proceed with cointegration testing. Ideally, variables used for cointegration testing should be stationary or I(1), where I(1) indicate that a variable was non-stationary in its level form, and was subsequently made stationary in its first differenced form. Stationarity is generated for each variable by taking the natural log of each variable and differencing it, thus achieving constant mean and variance for each variable. The subsequent determination of stationary for each variable was achieve by testing the stationarity of each variable via a series of unit root tests namely, the Augmented Dickey-Fuller (ADF) test, the Phillips-Perron (PP) test, and finally the KPSS test.

The following two tables illustrate the result of ADF testing executed on each variable in both its log and first order differenced form.

| | Variable | ADF | T-Statistic | Critical Value | Result |
|---|---|---|---|---|---|
| LOG FORM | LGDP | ADF(2) | -1.8088 | -2.8029 | **Non-Stationary** |
| | LENG | ADF(1) | -1.0992 | -3.6058 | **Non-Stationary** |
| | LFC | ADF(1) | -3.0965 | -3.6058 | **Non-Stationary** |

| | Variable | ADF | T-Statistic | Critical Value | Result |
|---|---|---|---|---|---|
| 1ST DIFF | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| | DGDP | ADF(1) | -5.8902 | -2.9435 | **Stationary** |
| | DENG | ADF(1) | -4.0183 | -2.9435 | **Stationary** |
| | DFC | ADF(4) | -3.7841 | -2.9703 | **Stationary** |

The above results are in line with researcher expectations where variables are expected to be non-stationary in their level or log form and stationary in their first differenced form. Furthermore, real world economic data is expected to display trend or theoretical characteristics in their level form that is otherwise non-stationary.

To further confirm variable stationarity, we ran the PP test on each variable in both its level and differenced form. Below are the tabulated results.

| | Variable | PP | T-Statistic | Critical Value | Result |
|---|---|---|---|---|---|
| LOG FORM | LGDP | | -4.8024 | -2.9424 | **Stationary** |
| | | | -1.4995 | -3.5659 | **Non-Stationary** |
| | LENG | | -1.9397 | -2.9424 | **Non-Stationary** |
| | | | -1.2027 | -3.5659 | **Non-Stationary** |
| | LFC | | -1.9270 | -2.9424 | **Non-Stationary** |
| | | | -1.3609 | -3.5659 | **Non-Stationary** |

| | Variable | PP | T-Statistic | Critical Value | Result |
|---|---|---|---|---|---|
| 1ST DIFF. FORM | DGDP | | -5.3923 | -2.8520 | **Stationary** |
| | | | -8.1326 | -3.5693 | **Stationary** |
| | DENG | | -6.7797 | -2.8520 | **Stationary** |
| | | | -8.2294 | -3.5693 | **Stationary** |
| | DFC | | -2.7175 | -2.8520 | **Non-Stationary** |
| | | | -2.8244 | -3.5693 | **Non-Stationary** |

The above results indicate inconsistency in the results of variable stationary compared to the previous ADF test, and furthermore illustrate conflicting stationary hypothesis with regards to variables in its level and differenced form, specifically the variables LGDP and DFC.

As a result of the above conflicting results we conducted the additional KPSS test as recommended by literature to better discern tests for variable stationarity. Below are the tabulated results of the KPSS test conducted on all variables in its level and differenced form.

| | Variable | KPSS | T-Statistic | Critical Value | Result |
|---|---|---|---|---|---|
| LOG FORM | LGDP | | 0.44235 | 0.37805 | **Non-Stationary** |
| | | | 0.14407 | 0.18593 | **Stationary** |
| | LENG | | 0.37213 | 0.37805 | **Stationary** |
| | | | 0.13415 | 0.18593 | **Stationary** |
| | LFC | | 0.44857 | 0.37805 | **Non-Stationary** |
| | | | 0.16045 | 0.18593 | **Stationary** |

| | Variable | KPSS | T-Statistic | Critical Value | Result |
|---|---|---|---|---|---|
| 1ST DIFF. FORM | DGDP | | 0.3984 | 0.37805 | **Non-Stationary** |
| | | | 0.18943 | 0.18593 | **Non-Stationary** |
| | DENG | | 0.29059 | 0.37805 | **Stationary** |
| | | | 0.13938 | 0.18593 | **Stationary** |
| | DFC | | 0.31228 | 0.37805 | **Stationary** |
| | | | 0.23363 | 0.18593 | **Non-Stationary** |

It is evident from the KPSS tests that inconsistency presented in the stationarity of each variable becomes more prevalent. Conflicting results are reported for almost every variable except for DENG. As a result of these unit root tests we find that our regressors are both I(1) and I(0) thus, we cannot proceed with normal approaches of cointegration testing associated with Engle and Granger (1987) and the maximum likelihood test based on Johansen (1988). For these reasons, we resort to the Auto Regressive Distributed Lag (ARDL) approach which does not retain the same limitations as the former approaches where regressors must be I(1), instead the ARDL approach can be applied if regressors are either I(1), I(0), or both. In that case of our research, all three of our variables consist of I(1) and I(0) stationarity, and accordingly proceed with using the ARDL technique to test long run cointegrating relationships amongst the variables.

The ARDL procedure begins with testing the presence the long run relationship between economic growth and energy consumption. We achieve this by testing the significance

of the lagged level of our variables GDP, ENG, and FC in the error correction form of the principal ARDL model.

The table below show the F-Statistics for testing the existence of long-run relationship between all our variables.

| Variable Addition Tests | |
|---|---|
| LGDP | 5.3288 [.008]* |
| LENG | 1.5809 [.229] |
| LFC | 5.6171 [.007]* |

*significant at 5% level, with critical value bound 4.066 – 5.119 taken from Pesaran et. al (2001), unrestricted intercept and no trend with 3 regressors.

The results of the above variable addition test indicate that when Economic Growth (GDP) and Fixed Capital Formation (FC) are treated as the dependant variable, there exists the presence of non-spurious long-run relationship among the variables. For the purpose of this empirical research we will proceed with using FC to explain the long-run relationship between economic growth (GDP), energy consumption (ENG), and fixed capital formation (FC). Following this we move on to confirm the exogeneity and endogeneity of the three variables.

**Static Long-Run Results**

We estimate the ARDL model based on the Akaike Information Criterion (AIC) as we have found no issue with our model while using AIC in the diagnostics tests of normality. Due to the similarity in standard errors under AIC and SBC, we determined that there will be a lesser probability of making a Type 1 and Type 2 error as a result.

Below are the tabulated static long-run results (ARDL estimates) and diagnostic test statistics of our above estimated model.

| Variable | Coefficient | Standard Error | T-Ratio |
|---|---|---|---|
| LGDP | 0.9283 | 0.27919 | 3.3249[.002]* |
| LENG | -0.031508 | 0.049069 | -.64212[.526] |

| Diagnostic Tests | | |
|---|---|---|
| Test Statistic | LM-Version | F-Version |
| A:Serial Correlation | CHSQ(1) = 1.4481[.229] | F(1,28) = 1.2085[.281] |
| B:Functional Form | CHSQ(1) = .041228[.839] | F(1,28) = .033021[.857] |

| | | |
|---|---|---|
| C:Normality | CHSQ(2) = 3.6337[.163] | Not applicable |
| D:Heteroscedasticity | CHSQ(1) = .024001[.877] | F(1,33) = .022645[.881] |

**Long-Run Estimates based on AIC-ARDL (2,1,0).**
Dependent variable is LFC, *indicate significance at 1% level, and no problem detected in the AIC diagnostics test.

From the results of the ARDL estimates above, we can deduce that LGDP has the expected positive sign and is statistically significant, while LENG has a negative sign and does not exert statistically significant effects on Fixed Capital Formation which is theoretically assumed. That being said, the above results indicate that for Singapore, with every 1% increase in GDP growth Fixed Capital Formation will increase by 0.92% while any increase in energy consumption leads to no significant effect on Fixed Capital Formation. While these results are incongruent with previous literature assumption of energy consumption on economic growth, when considered together with the previous result of long-run relationship cointegration, it does inform us that the added variable of Fixed Capital Formation, used as a proxy for economic growth, displays long-run relationship between Energy Consumption and Economic Growth, but there is a likelihood of short-run deviation from the long-run equilibrium with respect to Energy Consumption.

To better understand this long-run and short-run relationship between the variables, we attempted to utilise the Error Correction Representation for our ARDL model to determine the exogeneity and endogeneity of our variables as well as their speed of adjustments.

**Short-Run Dynamics**

The short-run dynamics of our ARDL model is illustrated in the tables below.
The table below illustrates short-run dynamics of our variables when LFC (Fixed Capital Formation) is taken as the dependant variable.

| Variable | Coefficient | Standard Error | T-Ratio |
|---|---|---|---|
| dLGDP | 0.9283 | 0.27919 | 3.3249[.002]* |
| dENG | -0.031508 | 0.049069 | -.64212[.526] |

| | | | |
|---|---|---|---|
| ecm(-1) | -0.22717 | 0.07262 | -3.1282[.004]* |

ecm = LFC -1.5603(LGDP) + .13870(LENG) - 9.3724(INPT)

| | | | |
|---|---|---|---|
| R-Squared | .64479 | R-Bar-Squared | .58354 |
| S.E. of Regression | .055700 | F-Stat. F(4,30) | 13.1603[.000] |
| Mean of Dependent Variable | .064617 | S.D. of Dependent Variable | .086311 |
| Residual Sum of Squares | .089971 | Equation Log-likelihood | 54.7004 |
| Akaike Info. Criterion | 48.7004 | Schwarz Bayesian Criterion | 44.0344 |
| DW-statistic | 2.2497 | | |

**Short-Run Dynamic Results (dependent variable dFC)**
*indicate significance at 1% level, LFC here is endogenous

Overall, the coefficient results of our short-run dynamics test indicate that our variables having the same expected signs as those indicated in the previous static long-run test. That being said, the above results illustrate an ecm value of -0.22717, significant at level 1%. As a result we can observe that there exists partial adjustment between the above variables as the coefficient falls between the bounds 0 and -1. While the speed of adjustment is close to zero, indicating slow adjustment in the long-run, its significance also implies that 22% of the disequilibrium caused by the previous year's shocks will converge with the long-run equilibrium in the current year. Furthermore, similar to the static long-run test LGDP is statistically significant. It means that GDP effects are relatively strong or exogenous on Fixed Capital Formation. This is in line with the theoretical assumption that GDP influences Fixed Capital Formation, especially highlighted by previous literature where Singapore's rapid urban development and technological advancements are a result of sustained and rapid economic growth. Similar to results indicated by static long-run estimations, the above results indicate that for every 1% increase in GDP growth, Fixed Capital Formation increases by 0.92%.

Furthermore, the significance of the ecm coefficient's t ratio at level 1% indicate that Fixed Capital Formation is in fact endogenous, and while the table also illustrates the significance of the variable LGDP at level 1%, the results imply that there exists a presence of unidirectional Granger causality running from GDP to Fixed Capital Formation.

Interestingly enough, this research used Fixed Capital Formation as a proxy for Economic Growth so as to construct a multivariate model that would enhance this research's estimation approach.

As a result of the above findings, we understand that the inclusion of Fixed Capital Formation as a proxy for GDP growth may further skew our paper's results.

The table below illustrates short-run dynamics of our variables when LENG (Energy Consumption) is taken as the dependant variable.

| Variable | Coefficient | Standard Error | T-Ratio |
|---|---|---|---|
| dLGDP | 1.0424 | .55962 | 1.8626[.072] |
| dLFC | -.023669 | .17449 | -.13564[.893] |
| ecm(-1) | -.17056 | .11242 | -1.5171[.139] |

ecm = LENG -.86872(LGDP) + .13877(LFC) - 2.8711(INPT)

| | | | |
|---|---|---|---|
| R-Squared | .17726 | R-Bar-Squared | .067563 |
| S.E. of Regression | .12292 | F-Stat. F(3,31) | 2.1545[.113] |
| Mean of Dependent Variable | .022299 | S.D. of Dependent Variable | .12730 |
| Residual Sum of Squares | .45330 | Equation Log-likelihood | 26.4016 |
| Akaike Info. Criterion | 21.4016 | Schwarz Bayesian Criterion | 17.5133 |
| DW-statistic | 2.0318 | | |

**Short-Run Dynamic Results (dependent variable dLENG)**

[+]LENG here is exogenous

The above table indicates that the t-ration of the ecm coefficient is not statistically significant at any level, and while it displays the right sign and is close to zero in absolute terms, its results cannot be utilised for this research. However, because we have failed to reject the null hypothesis of exogeneity, the results indicate that there is no adjustment done on the part of Energy Consumption in the long-run as it appears to be an exogenous variable. Therefore, it can be implied that no Granger causality runs from Energy Consumption to Economic Growth, which is surprising to us but not entirely different from some past literature.

The table below illustrates short-run dynamics of the variables when LGDP (Economic Growth) is taken as the dependant variable.

| Variable | Coefficient | Standard Error | T-Ratio |
|---|---|---|---|
| dLENG | .026821 | .041173 | .65142[.521] |
| dLFC | .19208 | .072135 | 2.6628[.013]** |
| ecm(-1) | .069087 | .064958 | 1.0636[.298] |

ecm = LGDP -.37178(LENG) -.82219(LFC) + 13.7437(INPT)

| | | | |
|---|---|---|---|
| R-Squared | .68497 | R-Bar-Squared | .53430 |
| S.E. of Regression | .027149 | F-Stat. F(9,25) | 5.5565[.000] |
| Mean of Dependent Variable | .042527 | S.D. of Dependent Variable | .039783 |
| Residual Sum of Squares | .016952 | Equation Log-likelihood | 83.9097 |
| Akaike Info. Criterion | 71.9097 | Schwarz Bayesian Criterion | 62.5776 |
| DW-statistic | 2.4452 | | |

**Short-Run Dynamic Results (dependent variable dLGDP)**
**indicate significance at 5% level, LGDP here is exogenous

Similar to the previous results of short-run dynamics, the above table indicates an ecm coefficient that is not significant at any level, indicating that null hypothesis of exogeneity cannot be rejected. However, it is interesting to note that the ecm coefficient is negative and different from the expected negative sign even though it is extremely close to zero in terms of absolute value. Furthermore, it can be noted that dLFC is found significant at level 5%, however due to the t-ratio of the ecm coefficient being not statistically significant, it would be spurious to further interpret the result of dLFC. Therefore, it can be observed that based on the above results no granger causality runs from Energy Consumption (ENG) to Economic Growth (GDP).

As a consequence of the short-run dynamic results illustrated above, we can conclude that no granger causality runs from Economic Growth (GDP) to Energy Consumption and vice versa. In a surprising turn of events, it can also be noted that there exists the presence of unidirectional Granger causality from GDP to Fixed Capital Formation despite our prior inclusion of the variable as proxy for Economic Growth in Singapore.

## Limitations

The objective of this empirical research was to find the causal or lead-lag relationship between economic growth and energy consumption in Singapore, and while our attempts to use the ARDL bounds approach to estimate this relationship, it was not ideal to utilize a

bivariate equation. As a result we included the variable of fixed capital formation as a proxy to better ascertain the effects of GDP on Energy Consumption and vice versa. With the addition of the variable to the model formerly consisting of only GDP to represent economic growth and energy use to represent energy consumption, the results of our ARDL approach not only implied the presence of a neutrality hypothesis between GDP and energy consumption, but it highlighted the presence of unidirectional Granger causality flowing from GDP to the added variable, fixed capital formation. While the detection of the unidirectional Granger causality from GDP to fixed capital formation was not a research objective, we can surmise that the result may be a good indicator of future research into the GDP and capital formation nexus of Singapore's economy.

Furthermore, the small sample size, although ideal for the ARDL bounds approach, may have contributed to the unexpected results as well. In addition, as we were unable to ascertain a proper lag order (results varied from 1 to 6) to further subsequent tests pertaining to this research, we understand that perhaps fixed capital formation was not an ideal variable to be included in an empirical study of this nature.

Finally, while the government of Singapore had begun considerable efforts to reduce energy consumption through a series of energy polices from the years 2007 to 2013, we had declined to include energy policies as a dummy variable as the inclusion of dummy variables were not a concerted inclusion into previous causality literature in the past.

## Conclusion and Policy Implications

The objective of this study was to evaluate the energy consumption and economic growth nexus in Singapore, where the aim was to identify the direction of causality between GDP and energy consumption with particular reference to the Singaporean economy. The data used spanned 39 years starting from 1975, and a proxy variable for GDP growth, Fixed Capital Formation was added to better explain the effects of energy on economic growth. Based on our analysis we found evidence of the neutrality hypothesis between energy consumption and economic growth in Singapore, where our ARDL tests showed no presence of long-term causal relationship between the two. As a result have concluded that in terms of policy implications, Singapore's ongoing efforts to reduce energy consumption via targeted energy policies such as

the Energy Conservation Act 2012, and its ratification with the Doha Amendment, would not result in negative repercussions on the country's economic growth in the long-run. Singapore's stable economic growth appear to be driven by other factors stronger than energy consumption, nor does its rapid economic growth show viable impact on energy consumption as illustrated by our research. Ultimately, the results of our research confirmed the neutrality hypothesis initially investigated on Singapore by Masih and Masih (1996), albeit through a different cointegration approach.

More surprisingly, was our discovery of a unidirectional causal relationship running from GDP to Fixed Capital Formation. Since this particular relationship was not an objective of our research we did not expand further into the implications and examination of its result, but we believe that this information may be useful to future researchers exploring the lead-lag relations between Singapore's economic growth and other economic indicators.

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