The effect of mismatched supply and demand of electricity on economic growth in South Africa

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Abstract

Since 2008, the South African economy has experienced several power cuts (unplanned or as part of a load-shedding schedule), presumably because of the inability of the electricity supply to cover the demand. This paper examines the impact of such a demand-supply mismatch on the country's economic growth within a production function framework. To do so, we use an Autoregressive Distributed Lag Model (ARDL) for the period 1985 to 2019. The paper finds that a positive mismatch (or surplus) of electricity (supply>demand) boosts economic growth in the long run. This finding provides evidence that supports the necessity of electricity supply expansion and the promotion of energy efficiency measures that both will create a mismatch (surplus) conducive to economic growth.

Keywords: Electricity, Energy, South Africa, Mismatch

List of Acronyms

ADF	Augmented-Dickey Fuller test
AIC	Akaike Info Criterion
ANC	African National Congress
ARDL	Autoregressive Distributed Lag
CO2	Carbon dioxide
CSIR	Council for Scientific and Industrial Research
CV	Critical Values
EKC	Environmental Kuznets Curve
GDP	Gross Domestic Product
LM	Lagrange Multiplier
MM,	Mismatch between demand and supply
NER	National Energy Regulator
OECD	Organisation for Economic Cooperation and Development
PP	Philipps-Perron
TFP	Total Factor Productivity
TO	Trade Openess
K	Capital stock

1. Introduction

South Africa's electricity is predominantly supplied by Eskom, the state-owned electric power producer. Recently, Eskom has faced governance issues that have caused challenges in its ability to provide electricity efficiently. These challenges include a liquidity decline necessitating South African government bailouts, the rapid deterioration of electricity generation plants, and Eskom's inability to adequately supply electricity to meet aggregate demand, which has resulted in the implementation of load-shedding in South Africa. Load-shedding occurs when Eskom cannot meet its portion of the national electricity demand and opts to periodically switch parts of its national electricity supply network to specific areas to distribute the limited electricity supply that it has pretty. When a geographic area is experiencing a period of load-shedding, it cannot access the electricity provided by Eskom during this time (Eskom, 2019).

South Africa has endured periodic energy crises since 2008 that have rendered electricity supplied insufficient to meet electricity demand. The *Energy Security in South Africa* Report (Trollip, Butler , Burton , Caetano , & Godinho, 2014) found that in 2014, electricity alone accounted for 28% of total energy usage in South Africa. The report further found that 95% of this electricity is locally generated (Trollip, Butler , Burton , Caetano , & Godinho, 2014). Hence, the failure to supply electricity sufficiently has created a perception of electricity insecurity amongst consumers and suppressed demand for electricity. Consumers are made aware of the inability of electricity generation to meet their demand by implementing periodical load-shedding where access to electricity provided by Eskom is temporarily halted (Eskom, 2019). As such, the electricity shortage hampers both usage and access to electricity.

The fundamentals of microeconomic theory show that when there is a mismatch between the supply and demand of a good (a shortage or a surplus), resource allocation in that market is suboptimal. This suboptimality most overtly presents itself in South Africa's case as the electricity shortage. The consequences of this shortage, should they be significant enough, can potentially affect other sectors in an economy. If this is the case, the electricity shortage ultimately could become a barrier to income generation in the economy and thus, hamper economic growth and development. South African businesses have suffered significant losses because of electricity unsustainability. Industrial growth, and therefore, economic growth has been severely dampened by load-shedding effects. These losses are partly because of the logistical issues caused by load-shedding (such as damage to equipment) and the inadequate investment made by businesses into mechanics that could mitigate the adverse effects of load-shedding (Ateba, Prinsloo, & Gawlik, 2019). To address the negative impact of load-shedding, improving electrical infrastructure is one remedy that South African households have expressed to favour (Nkosi & Dikgang , 2018).

The mismatch in electricity consumption and supply is similar to the reserve margin of a nation's electricity producers. A reserve margin is defined as the difference between the maximum supply of electricity available for distribution and the maximum expected demand as a proportion of the market. A reserve margin is essentially a contingency measure against unforeseen supply and demand characteristics. Reserve margins need to be managed appropriately (Energy Information Administration, 2012). If a power producer's reserve margin is too large, this inflates electricity prices.

On the other hand, a low or non-existent reserve margin yields elongated periods of electricity blackouts when demand exceeds supply or an electricity generator unexpectedly malfunctions (Eskom, 2020). The mismatch discussed in this paper goes beyond the scope of a reserve margin. This paper defines the mismatch between electricity consumption and supply as the subtraction of national electricity consumption from the national electricity supply. A mismatch between electricity supply and demand shows the inability of these variables to meet even when a power producer's reserves are used. Furthermore, the mismatch accounts for when reserves need not be utilised due to consumer demand meeting supply expectations or even falling short of these expectations. The reserve margin alone cannot account for the culmination of these electricity market dynamics. Since actual electricity demand is difficult to determine, electricity consumption is used to proxy electricity demand. As such, electricity consumption and electricity demand are used interchangeably throughout this paper.

In comparison to the extensive research done on the effect of energy consumption on economic growth and energy supply on economic growth, there exists limited literature discussing the impact on the economic development of a mismatch (surplus or shortage) between energy consumption and supply internationally (Muhammad, 2015; Ju, Yoo, & Kwak, 2016; Perwez, Sohail, Hassan, & Zia, 2015; Orioli & Di Gangi, 2013) and even less in South Africa (Trollip, Butler , Burton , Caetano , & Godinho, 2014; Spalding-Fecher, et al., 2017). The policy discussion in South Africa in the last decade attributes the load-shedding and its negative consequences to the economy on the energy demand and the inadequacy of the electricity capacity to cover it. Also, in an economy with challenging conditions, financial resources and government budget does not allow for overinvestment towards energy infrastructure.

So, this paper aims to examine the impact of such a mismatch on the country's economic growth within a production function framework. We use an Autoregressive Distributed Lag Model (ARDL) for the period 1985 to 2019 to establish a long-run relationship amongst the mismatch, economic growth and other determinants of economic growth in the South African economy within a production function theoretical framework. Section 2 presents a literature review to illustrate the interaction between economic growth and the electricity market. Section 3 then further contextualises South Africa's mismatch by providing a historical account of how the South African mismatch has evolved. Section 4 accounts for the methodology used in this paper and presents the data to which this methodology will be applied. Section 5 provides an interpretation of this paper's empirical findings, while Section 6 reconciles these findings and provides a way forward.

2. Literature review

Historically, resource and energy economists have argued and provided evidence that energy plays a significant role in economic growth and development. Stern (2004) explains that empirical modelling has confirmed that energy is a vital factor in the growth process. A study done across 100 countries found that wealthier countries have higher correlations between their electricity usage and their ability to generate wealth than poorer countries (Ferguson, Wilkinson, & Hill, 2000). This fact implies that the more electricity a country uses, the more likely this country will be to develop; vital implication for a currently developing country like South Africa. The relatedness of energy and economic growth is evident in the determinants of both factors. In South Africa, consumer income (an indicator for GDP per capita) is the most crucial determinant of electricity demand in the long run (Amusa, Amusa, & Mabugu, 2009). Endogenous growth theory attributes the primary determinant of long-run economic growth to total productivity dependent on technological advancement (Howitt, 2004). Assuming that the generation of technological advancements requires electricity, long-run economic growth is achieved, given that electricity is used at some point within the technical advancement process. Thus, electricity and economic growth exhibit characteristics that could suggest an intense co-dependence.

The quest to examine a causal relationship between energy[1] (particularly electricity) and economic growth in an economy has predominantly been studied in two ways. The potential causality between energy consumption and economic growth is tested, or the possible causality between energy supply and economic growth is tested. When the causality relationship between energy consumption and economic growth is assessed, there are four potential directions that this causal relationship can take.

[1] Electricity is one of the components of energy. Although the energy market is far broader than the electricity market, it is useful to use general trends in the energy market to better understand the electricity market. Thus, throughout the paper, energy market outcomes are used to describe and understand the electricity market.

These possible directions of causation are summarised by Inglesi-Lotz & Pouris (2016). According to this summary, the first is termed the Growth hypothesis. In this scenario, there is a causal relationship such that changes (trends) in energy consumption cause changes (trends) in economic growth. The second potential direction of causation is the Conservation hypothesis, where energy consumption is caused by economic growth. The Neutrality hypothesis occurs when there is no causal relationship between energy consumption and economic growth, while the Feedback hypothesis accounts for a bidirectional causal relationship between these variables.

Global studies have come to varying conclusions about the direction and existence of a causal relationship between energy consumption and economic growth, even for the same countries. One reason for this is the existence of several statistical approaches to examining causality. For example, a study for the United States case found that energy consumption unidirectionally Granger causes economic growth using three models. In comparison, two different models determined the relationship to follow the Feedback hypothesis (Stern D. , 2000). Even when countries are categorised as highly developed OECD countries, there is no evidence of commonality in these countries energy and economic growth causal relationships (Yildirima & Aslanb, 2012). For South Africa, by 2016, a limited number of studies, as discussed in Inglesi-Lotz and Pouris (2016) had been done to examine the causality between energy consumption and economic growth. There was no consensus reached amongst these studies about whether or not there is a causal relationship between energy consumption and economic growth, nor about the direction of the causality in cases where such a relationship was found (Inglesi-Lotz & Pouris, 2016; Ranjibar, Chang, Nel , & Gupta , 2017). The studies examining the South African case have had mixed results:

- the neutrality hypothesis (Bah & Azam, 2017),
- the growth hypothesis (Acheampong, 2018) and (Bekun, Emir, & Sarkodie, 2019))
- feedback hypothesis (Khobai & Le Roux, 2017),
- while Dlamini et al. (2016) stressed the change of direction over time.

Compared to these studies, fewer studies have been done to test the relationship between energy supply and economic growth in South Africa. However, a recent study found that electricity supply, amongst other variables, has a long-run positive relationship with economic growth in South Africa (Khobai, Abel, & Le Roux, 2016). Other international case studies on energy supply and economic growth reinforce the vast potential for differing causal relationship outcomes across countries. For example, a study done for Nigeria found that energy supply significantly impacts economic growth (Samuel & Lionel , 2013), while a similar study done for Portugal found evidence of a bidirectional causality relationship between energy supply and economic growth (Cerdeira & Paulo, 2012).

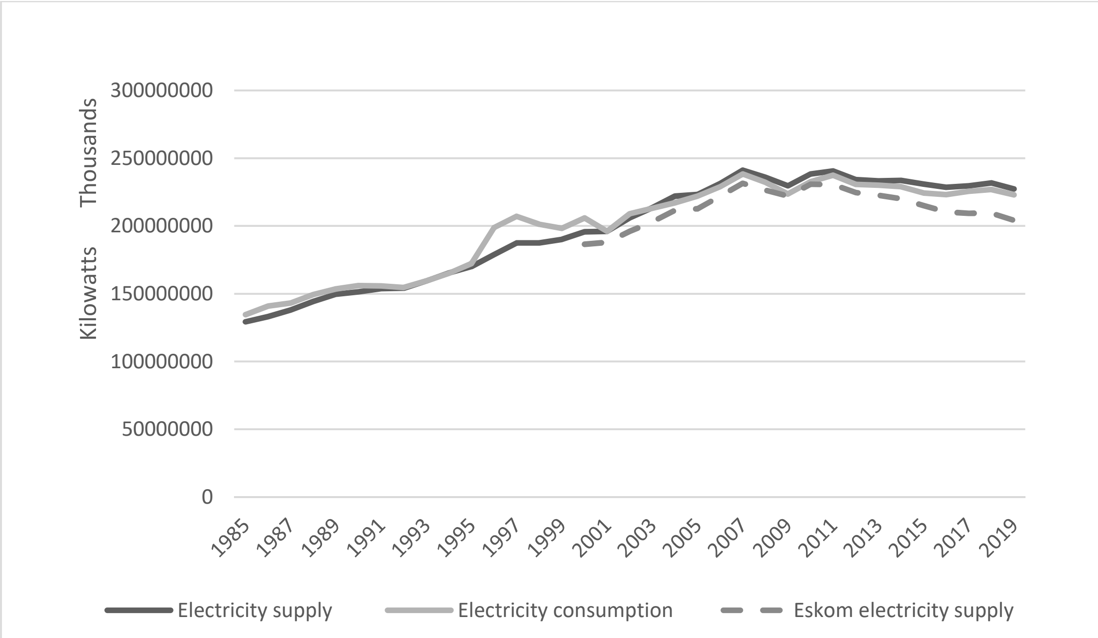
Merging these two common approaches to choose consumption or supply as a proxy of electricity conditions to examine the causality relationship between energy and economic growth would entail studying the effect of both electricity consumption and supply on economic growth. The interlinkage between the electricity market and economic growth is indisputable. Thus, inefficiency in the South African electricity market resulting from factors such as load-shedding might be significant enough to impact economic growth. Similarly, the persistently low levels of economic growth in South Africa may also be affecting the electricity market. Hence, there is enough evidence in the literature to suggest a relationship between the mismatch of electricity supply and demand and economic growth in South Africa that is worth investigating.

3. Contextualising the South African electricity mismatch

A demonstration of the fact that a mismatch exists in the South African electricity sector is shown in Figure 1 below. This graph accounts for Eskom's inability to meet national consumption from 2002, a year after the entity became a state-owned enterprise (Public Affairs Research Institute , 2013). Eskom's electricity supply has failed to meet the national electricity consumption level leading to severe power cuts and load-shedding since about 2010. Since Eskom is South Africa's leading electric power generator, it is reasonable to assume that Eskom's declining power supply levels indicate the decline in national electricity production levels. However, it could be the case that other power producers have accounted for this mismatch. Hence, this paper will consider South Africa's mismatched electricity consumption and supply by all electricity producers instead of only Eskom.

Figure 1 indicates that electricity supply and demand have seemingly seldom intersected. Notably, directly after a perfect alignment between electricity supply and demand from 1992 to 1993, an unprecedented spike in the mismatch occurred between 1994 and 2002. Upon further investigation into Eskom, South Africa's largest electricity generator, one can find evidence to explain this anomaly. In 1991 the Eskom 'mass electrification programme' was announced (Public Affairs Research Institute , 2013). This 'electrification for all was to be implemented to meet the expected rise in electricity access capabilities amongst non-white South Africans given that South Africa was moving towards democracy. In 1995, one year after South Africa's first democratic election, Eskom already began to encounter some difficulty. The newly established National Energy Regulator (NER) struggled to regulate Eskom and other electrifying bodies due to the NER's inability to accumulate sufficient capacity to do so (Public Affairs Research Institute , 2013). It follows that if Eskom's regulation was inefficient, then the power producer's electricity provision was probably inadequate too, and hence, the notable spike in the mismatch between 1994 and 1998.

Figure 1 *- Electricity supply and consumption in South Africa in kilowatts,1985-2019*



Sources: Statistics South Africa (2020) and The World Bank (2020).

The White Paper on South Africa's Energy Policy post-Apartheid was officially tabled in 1998 (Republic of South Africa). The White paper noted that in the past, Eskom had oversupplied electricity because of poor investment decisions. The burden of which fell to consumers. The White paper put forward some unprecedented reforms to the electricity sector, including the encouragement of independent power producers to enter the electricity market and the restructuring of Eskom into separate entries for generation and transmission. The White paper envisaged a new 'integrated planning' system to facilitate these goals, which would account for electricity suppliers and consumers of electricity, who had been previously marginalised in the electricity market's planning processes (Republic of South Africa, 1998). From 1999, the plan began its implementation phase. The result of which yielded some positive outcomes in the electricity sector as the mismatch became less pronounced.

The electricity market mismatch reached an all-time low in 2001, signalling that the demand and supply of electricity had finally aligned. This result was fleeting, though, as Eskom soon ran into some issues again. The same year, Eskom was converted into a state-owned enterprise to manage more efficiently (Public Affairs Research Institute , 2013). Furthermore, this policy move accompanied the South African government's plans to restructure Eskom and sell parts of it to private stakeholders.

Eskom would ultimately take up a significantly lower portion of the electricity generation market (from 96% to a proposed 70%). The proposal to restructure and sell parts of Eskom was met with fierce opposition from the Eskom CEO at the time, Thulani Gcabashe, and from organised labour bodies, such as the Congress of South African Trade Unions. They opposed the upward price pressure that this proposal would place on the past relatively low Eskom electricity selling prices, which had prevailed.

From 2002 to 2008, National supply and consumption generally increased together over time, rendering the mismatch relatively small. It, therefore, seems that the policy moves to make Eskom a state-owned enterprise yielded better coordination between electricity supply and demand. That this result was a product of excellent governance is possible but unlikely. In 1997, Eskom's installation of additional generation capacity meant that the enterprise would have surplus electricity generation capacity until 2007 (Public Affairs Research Institute , 2013). Therefore, it is likely that these electricity reserves gradually declined as Eskom finally attempted to meet its consumers' electricity demand. In so doing, creating a pseudo efficiency impression in the electricity market where the mismatch was relatively small. Rather, Eskom was depleting its reserves to meet electricity consumption from 2002 to 2008. The initial spike in the mismatch and then rapid reversion to a zero-kilowatt mismatch per employed person is expected between 1995 and 2008. However, from 2008 onwards, electricity consumption began to mimic electricity supply to maintain a relatively constant mismatch. In 2008, Eskom ran out of reserves, and the energy supply crisis ensued (see the break in Figure 1). Furthermore, from 2008 onwards, Figure 1 indicates an oscillation of the mismatch between a relatively constant mean, indicating the haphazard trend displayed by the electricity sector since 2008.

While Eskom has struggled to meet national demand, it is essential to note that Figure 1 accounts for the total national electricity supply. Therefore, there is an apparent surplus in electricity supplied from 2005 onwards. However, this surplus does not necessarily translate to the amount of electricity available for household and business consumption. It includes the total production of electricity by independent power producers and Eskom (Statistics South Africa, 2020). In other words, South Africa has a specific capacity for generation and supply, but that does not always translate to access to the national grid, particularly in remote rural areas.

4. Methodology and data

This section presents the study's theoretical framework, econometric methodology and used dataset for the analysis.

4.1. Theoretical framework

A discussion by Howitt (2004) on new endogenous growth theory noted that contributions to neoclassical growth theory had been challenged by Romer (1994) and Lucas (1988) . With these unique contributions, the new endogenous growth theory has emerged as a stream of economic growth theory that hypothesises that a nation's long-run economic growth is driven mainly by its long-run growth rate of total factor productivity (TFP). Since the rate of TFP depends on the speed of technological advancement which comes from innovation, new endogenous growth theorists attribute economic growth rates mainly to relatively high rates of technological advances. Economic policy determines this technical progress rate, particularly about trade openness, competition, and education. Thus, policies that favour the increase in technological advancement increase the rate of TFP and, in turn, yield a rise in an economy's economic growth.

This paper uses a theoretical framework consistent with the endogenous growth theory that Samuel and Lionel have suggested. Samuel and Lionel (2013) emphasise the necessity to use an accurate growth model specification to obtain robust estimation results.

The general specification of the endogenous economic growth trajectory is:

$$Y = Af(K, L) - \quad (1)$$

Economic growth, Y, is determined by total factor productivity, A, as well as a function of capital accumulation, K, and employed persons, L. For simplicity, it is assumed that the levels of capital and labour are homogenous. Y is proxied by GDP.

Mismatched electricity supply and demand of the economy (Calculated by subtracting national electricity consumption from national electricity supply) is incorporated in the model through A. It has been shown that energy, and hence electricity, has a relationship with A (Ladu & Meleddu, 2014). One prominent channel through which this relationship could present itself is that one cannot innovate and, hence, use technological advancements without energy (particularly electricity). Furthermore, to reach the optimal level of technology transfer and, in turn, the optimal growth rate in A, energy (mainly electricity) must be used efficiently. In essence, for A to grow, energy productivity must grow too (Chang & Hu , 2010). A mismatch in electricity supply and demand is a clear indication of the contrary.

A's other essential components include innovation and economic institutions (policies) favouring economic growth (Srinivasan, 2005). Therefore, one proxy that partially accounts for national innovation levels and indicates the importance of innovation to a nation is its trade openness. Trade openness is measured as the sum of exports of goods & services and imports of goods & services divided by GDP (Fadiran & Akanbi, 2017). Specifically, South Africa would import innovations from abroad while exporting local creations to others. As noted by Howitt (2004), trade openness can potentially raise TFP through technology transfer. As goods and services are exchanged between nations, so are innovations. These innovations can be used to increase productivity, and the underlying model which developed these innovations can be learned and improved upon to add to the pool of invention. Policies in favour of trade openness would be an indication of a nation that partakes in technology transfer and thus, contributes to their TFP.

Furthermore, trade openness potentially affects productivity through gains to specialisation, increased intensity in competition and the creation of competitive advantages (Howitt, 2004). Therefore, the ability of trade openness to account for national innovation levels and the relative importance of a nation's policies on long-run economic growth make it an appropriate proxy for TFP. A similar approach has been used for the South African context (Khobai, Abel, & Le Roux, 2016). Therefore, trade openness and the mismatch serve to contribute to A in the South African economy uniquely.

$$A = f(MM, \mathrm{TO}) - (2)$$

Thus, TFP is a function of the mismatch in electricity supply and demand, MM, and trade openness, TO.

Substituting the equation of A into the economic growth function yields:

$$Y = f(MM, \mathrm{K}, TO, L) - (3)$$

For these proxies to be estimated in per capita terms, we divided by the number of persons employed, L:

$$y = f(MM, k, to) - (4)$$

The underlying regression model to be used for estimation is:

$$lny_t = \beta_0 + \beta_1 t + \beta_2 MM_t + \beta_3 lnk_t + \beta_4 lnto_t + \mu - \ (5)$$

Where *ln* is the natural logarithm of each variable and μ represents the stochastic error term. The parameters β represent the relationship with each of the explanatory variables with lny: β_2 is the coefficient for the Mismatch (MM), β_3 for Capital (lnk), and β_4 for trade openness.

β_{to} is the parameter for trade openness (to), β_{MM} for the Mismatch (MM), and β_k for the Capital. Therefore, three variables are ultimately divided by the number of employed people and then converted to natural logarithm form, namely, GDP, capital accumulation, and trade openness. The mismatch is not converted to its natural logarithm due to its negative values (mathematically, it is impossible to take a negative or zero value).

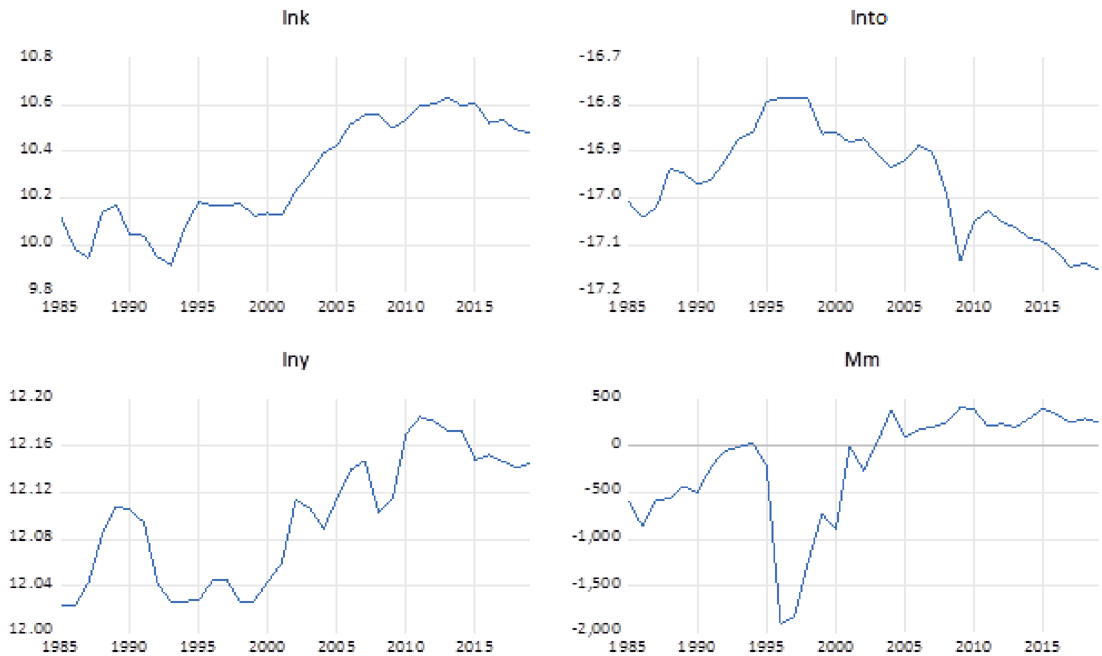
4.2. Data description

The data are sourced from the World Bank World Development Indicators (2020), Statistics South Africa (2020) as well as the Council for Scientific and Industrial Research (CSIR) (2019). Table 1 shows the source of each variable as well as its unit of measurement. The time series analysis will be done for a period ranging from 1985 to 2019. The Statistics South Africa data are sourced from the data used in the publication entitled "Electricity generated and available for distribution (Preliminary) May 2020". As described in the methodology, the relevant transformations for statistical estimation are made to each variable in the dataset.

Table 1: *Specification of dataset variables*

Name of the variable	Full description	Units of measurement	Source
Electricity generated and available for distribution in South Africa (Used for *MM)*	The total electricity supplied by all producers for South Africa.	Gigawatt hours	(Statistics South Africa, 2020)
Electric power consumption (Used for *MM)*	The total electricity consumed by South Africa is sourced from heat and power plants.	Gigawatt hours	(World Bank, 2020) for the period from 1985 to 2014 and (Statistics South Africa, 2020) for the period from 2014 to 2019 and
Trade openness (Used for *lnto)*	The sum of imported and exported goods and services as a proportion of GDP.	Percentage	(World Bank, 2020)
Capital Accumulation (Gross Fixed Capital Formation) (Used for *lnk)*	Improvements of land and purchases of and construction on capital equipment such as power plants (constant prices).	South African Rands	(World Bank, 2020)
GDP (Used for *lny)*	Gross Domestic Product (constant prices).	South African Rands	(World Bank, 2020)
Employed persons (Used for all variables)	Employed persons above the age of 15	Persons	(World Bank, 2020)

Figure 2 – Graphical representation of variables, 1985-2019



Further graphical inference allows for primary analysis of the other variables in the model. Each variable seems to exhibit a trend shift between 1994 and 1998. In 1994, South Africa's first democratic election took place (Republic of South Africa, 2019) with a subsequent upward effect in moist macroeconomic variables. lnt, exhibits a downward overall trend from 1997 onwards. A closer look at the data depicts a generally increasing trade openness ratio over time.

Similarly, employment has generally increased in South Africa over time. Since endogenous theory mandates that the trade openness ratio be divided by persons employed, this results in a tiny proportion for each observation. As persons used denominator increases, the increases in trade openness are seemingly much smaller in comparison because these are proportions. More broadly, for lny, *MM,* lnk and $lnto,$ the time period from 1994 to 2002 represent a time of volatility in the trajectories of these series, as shown in Figure 2.

Table 2: *Descriptive statistics*

	Mean	Median	Std. Dev.	Skewness	Kurtosis	Jarque-Bera stat	Jarque-Bera Prob.	Sum Sq. Dev.
lny	12.097	12.104	0.055	0.007	1.614	2.800	0.247	0.102
MM	-182.977	27.925	603.407	-1.373	4.333	13.584	0.001	12379408
lnk	10.301	10.232	0.234	-0.040	1.515	3.224	0.200	1.865
lnto	-16.965	-16.947	0.112	-0.106	1.942	1.698	0.428	0.426

The descriptive statistics in Table 2 indicate that, according to the Jarque-Bera test for normality, each variable in the model is normally distributed except Mm. Furthermore, Mm has a substantial standard deviation. This fact is expected because of the extreme volatility exhibited by Mm between 1994 and 2002. Again, Mm is not in natural logarithm form like the other model variables. As such, MM's trajectory is not "smoothed" after the logarithmic conversion, as the other variables are.

4.3. Econometric methodology

Menegaki (2019) argues that most studies in the broader energy-growth literature have employed the ARDL methodology due to their similar examined datasets and series distribution, but most notably due to the merits of ARDL: "flexibility, interpretability, eloquence, and statistical properties). As per Menegaki (2019), this paper adopts three steps to examine the relationships among the model's variables. These steps are in line with the methodologies used by other papers to examine cointegrating relationships (Lin, Inglesi-Lotz, & Chang, 2017, Inglesi-Lotz & Gupta, 2013; Odhiambo, 2009 and Rahman & Kashem, 2017). First, the stationarity of each variable in question is determined. Should the appropriate stationarity proprieties of each variable hold, steps two and three of the analysis can commence. Step two involves using the Autoregressive Distributed Lag (ARDL) test, which tests for the linear dependence of variables and hence, the co-integration between variables. ARDL is widely used in EKC studies because of its several advantages over the standard residual co-integration techniques. Firstly, it does not require the series under consideration to be integrated of the same order. Secondly, both short-run and long-run coefficients are simultaneously estimated. Thirdly, it uses lags of both dependent and explanatory variables, thereby helping to reduce serial correlation and endogeneity problems. Lastly, in small samples, ARDL performs better than the standard approaches to co-integration. Step three then ensures the robustness of the ARDL Results by assessing the diagnostics of the residuals of the ARDL equations of interest in this paper.

For the ARDL bounds test results using an ARDL model to be statistically sound and thus, interpretable; no variable should be integrated of order 2, I(2) (Rahman & Kashem, 2017). Therefore, the stationarity of each variable should be determined beforehand. For this reason, the Augmented Dickey-Fuller (ADF) test for unit roots is conducted. An ADF test is used to assess whether the series in a given model is stationary or not and, if they are not, what order of integration the series is. Thus, the series of interests are lny, Mm, lnt and lnk. If the ADF test finds that these variables are integrated of the same order (I.e. both I(0) or I(1)), this implies that the variables could be linearly related (cointegrated). If this is the case, the co-integration relationship between these variables can be assessed using the

ARDL model (Engsted & Bentzen, 1997). A cointegrating relationship implies the existence of a long-run relationship where the residual of the model is stationary.

First, to informally test for the stationarity of variables, a graphical representation is used, as shown in Figure 2. The patterns of these variables each exhibit volatility over time. As explained above, 1994-2002 played a notable role in the trajectory determinants of each variable in this model. Structural breaks in 1994 have been used in the unit root testing of lny, Mm and lnk, while 1997 has been used as a structural break for lnt .

The ARDL model is desirable for a time series energy dataset because of its relatively unrestrictive conditions on variables (Odhiambo, 2009). The ARDL model allows for regressors to be integrated of order 1, I(1), or for regressors to be stationary, I(0) (Engsted & Bentzen, 1997). Once the ADF test results confirm this criterion, the ARDL test becomes appropriate to examine the long-run relationship between the series in this model. Furthermore, energy variables are often slow to adjust in response to other variables such as GDP. The long-run relationship between the variables in this model is the relationship of interest for this paper. Thus, the ARDL's ability to differentiate between short-run and long-run relationships makes this approach well suited for the electricity data used in this paper (Bentzen & Engsted, 2001).

The variables in the model need to be altered to suit the ARDL form. The terms of the underlying regression model are lagged and differenced to adhere to the specifications of the ARDL bounds test. The appropriate values for the number of lags used in the model are determined with the Akaike Information Criterion (AIC). Since there are four variables in question, four equations (equations 6 to 9 below) are then subsequently set up based on a model similar to that used by Odhiambo in 2009. The equations follow those characterised as an "unconditional error correction model", such that the coefficients of the regressors are unrestricted (Rahman & Kashem, 2017).

The unconditional error correction models of the ARDL model that will be used to assess the long-run relationships between the variables in the model are:

$$\begin{aligned}\Delta lny_t = a_{0y} &+ \sum_{i=1}^{n} a_{1y} \Delta lny_{t-i} \\ &+ \sum_{i=0}^{n} a_{2y} \Delta MM_{t-i} \\ &+ \sum_{i=0}^{n} a_{3y} \Delta lnk_{t-i} + \sum_{i=0}^{n} a_{4y} \Delta lnto_{t-i} + \sigma_{1y} lny_{t-1} + \sigma_{2y} MM_{t-1} \\ &+ \sigma_{3y} \ln k_{t-1} + \sigma_{4y}\, lnto_{t-1} + \mu_{1i} \quad - (6)\end{aligned}$$

$$\Delta MM_t = a_{0MM} + \sum_{i=1}^{n} a_{1MM} \Delta MM_{t-i}$$
$$+ \sum_{i=0}^{n} a_{2MM} \Delta lny\_(t-i)$$
$$+ \sum_{i=0}^{n} a_{3MM} \Delta lnk_{t-i} + \sum_{i=0}^{n} a_{4MM} \Delta lnto_{t-i} + \sigma_{1MM} lny_{t-1} + \sigma_{2MM} MM_{t-1}$$
$$+ \sigma_{3MM} \ln k_{t-1} + \sigma_{4MM}\, lnto_{t-1} + \mu_{2i} \quad - (7)$$

$$\Delta lnk_t = a_{0k} + \sum_{i=1}^{n} a_{1k} \Delta lnk_{t-i}$$
$$+ \sum_{i=0}^{n} a_{2k} \Delta lny_{t-i}$$
$$+ \sum_{i=0}^{n} a_{3k} \Delta MM_{t-i} + \sum_{i=0}^{n} a_{4k} \Delta lnto_{t-i} + \sigma_{1k} lny_{t-1} + \sigma_{2k} MM_{t-1}$$
$$+ \sigma_{3k} \ln k_{t-1} + \sigma_{4k}\, lnto_{t-1} + \mu_{3i} \quad - (8)$$

$$\Delta lnto_t = a_{0to} + \sum_{i=1}^{n} a_{1to} \Delta lnto_{t-i}$$
$$+ \sum_{i=0}^{n} a_{2to} \Delta lny_{t-i}$$
$$+ \sum_{i=0}^{n} a_{3to} \Delta MM_{t-i} + \sum_{i=0}^{n} a_{4to} \Delta lnk_{t-i} + \sigma_{1to} lny_{t-1} + \sigma_{2to} MM_{t-1}$$
$$+ \sigma_{3to} \ln k_{t-1} + \sigma_{4to}\, lnto_{t-1} + \mu_{4i} \quad - (9)$$

Where: μ is the white noise error term in the model; Δ is the first difference operator; t denotes time in subscripts; i is the selected number of lags.

The ARDL bounds test uses a joint F-test to determine the significance of the lagged terms in the model. The null hypothesis for the absence of co-integration (H_0: No co-integration exists) is tested against the alternative hypothesis of the existence of co-integration (H_1: Co-integration exists) in this bounds test. The computed F-statistic is measured against an upper and lower bound value from a bounds critical value table suited for a small sample size (Narayan, 2005). This test is done for each equation in the model. Of particular interest to answering this paper's research question are Equations 6 and 7. The ARDL model's computed time series explanatory variable coefficients indicate the strength and direction of the potential long-run relationship between the model's time series variables (lny, MM, lnk and $lnto$) (Rahman & Kashem, 2017).

In particular, the ARDL test confirms or denies the above hypothesis by using a joint F-statistic test for equation 6 in the ARDL as follows:

$$H_0: \sigma_{1y} = \sigma_{2y} = \sigma_{3y} = \sigma_{4y} = 0 \; - (10)$$

$$H_1: \sigma_{1y} \neq \sigma_{2y} \neq \sigma_{3y} \neq \sigma_{4y} \neq 0 - (11)$$

And for equation 7

$$H_0: \sigma_{1MM} = \sigma_{2MM} = \sigma_{3MM} = \sigma_{4MM} = 0 \; - (12)$$

$$H_1: \sigma_{1MM} \neq \sigma_{2MM} \neq \sigma_{3MM} \neq \sigma_{4MM} \neq 0 - (13)$$

If the computed F-statistic is below the lower bound critical value, there is sufficient evidence to infer that no co-integration exists between the variables. Thus, H_0 is not rejected. On the other hand, if the computed F-statistic is larger than the upper bound critical value, there is enough evidence to infer that co-integration exists between the variables. Thus, H_0 is rejected. Should the computed F-statistic be in between the bounds, the result is inconclusive. Potentially, a 'Bounds t-test' can be used to get more information about the co-integration relationship between variables in such a case (Rahman & Kashem, 2017).

Finally, it is apt to assess the diagnostics of the residuals of our Equations of interest. In particular, for the ARDL result to be statistically valid, the residuals of each equation should be normally distributed and exhibit no serial autocorrelation (Rahman & Kashem, 2017). The first way this paper examines this is through graphical analysis. Then, to assess this formally, a Jacque-Bera test for normality and a Breusch-Godfrey Lagrange multiplier (LM) test for serial autocorrelation are conducted.

5. Empirical results

The results of the unit root tests are shown below in Table 3. Each variable in the regression of this model other than lnk is nonstationary and integrated of order 1. lnk is a stationary series. The variables, therefore, abide by the stationarity properties required of series' to be used in an ARDL analysis. For robustness, a Phillips-Perron (PP) test for stationarity is done to confirm that each variable in this model is integrated of order zero or one only. The PP test contained in the Appendix confirms this.

Table 3: *ADF Stationarity test results*

Series	Model	Modified ADF with a single breakpoint		
		Break date user-specified	Lags	$\tau_\tau,\ \tau_\mu,\ \tau$
lny	Trend & intercept (breaking trend & intercept)	1994	0	-1.484
	Intercept	1994	0	-1.780
	None (no trend or intercept)	--	--	--
Δlny	Trend & intercept (breaking trend & intercept)	1994	0	-5.086***
	Intercept	1994	0	-4.114**
	None (no trend or intercept)	--	--	--
Mm	Trend & intercept (breaking trend & intercept)	1994	0	-3.293
	Intercept	1994	0	-1.827
	None (no trend or intercept)	--	--	--
$\Delta\ Mm$	Trend & intercept (breaking trend & intercept)	1994	0	-5.327***
	Intercept	1994	0	-5.527***
	None (no trend or intercept)	--	--	--
lnk	Trend & intercept (breaking trend & intercept)	1994	0	-1.392
	Intercept	1994	0	-1.792
	None (no trend or intercept)	--	--	--
Δlnk	Trend & intercept (breaking trend & intercept)	1994	0	-5.496***
	Intercept	1994	0	-5.155***
	None (no trend or intercept)	--	--	--
$lnto$	Trend & intercept (breaking trend & intercept)	1997	0	-5.002***
	Intercept	1997	0	-1.080
	None (no trend or intercept)	--	--	--

(*/**/***) Statistically significant at a (10/5/1)% level

Table 4 shows an ARDL (4, 2, 4, 3, 2)[2] model for Δlny_t. Both ARDL models exhibit a long-run relationship amongst variables. This relationship is confirmed by comparing the F-statistics to the asymptotic critical value bounds of these ARDL equations. These statistics allow for the rejection of the null hypothesis that there is no long-run cointegrating relationship amongst the variables in the models at all significance levels. Therefore, *MM,* the mismatch per person employed, is a significant determinant of South African in the long run. Similarly, the mismatch is statistically significantly determined, in part, by *lny,* economic growth per person employed, in the long run. The Appendix contains the results of Equations 8 and 9.

From this, it is evident that *MM*, *lnk, lnto* and *d* each statistically significantly determine the level of lny between 1985 and 2019 in South Africa in the long run. A 1-unit increment in *MM* leads to a 0.0032% increase in *lny*, ceteris paribus. A 1% increase in *k,* capital accumulation per person employed, yields a 0. 214% increase in *lny*, ceteris paribus. All else equal, a 1% increase in *to* the trade openness level per person employed will lead to a 0.265% contraction in the South African economy per person

[2] The numbers denote the appropriate number of lags chosen for each variable of the regression.

employed between 1985 and 2019. The implication is that trade openness is harmful to the economy through the total factor productivity channel for the South African case. *d,* the dummy variable, accounts for the volatility in these variables during the transition to democracy and the lagged effects. Hence, *d* is equal to 1 between 1994 and 2002 and 0 elsewhere. The dummy variable assisted in creating a more realistic model so that a robust inference can be made accounting for economic shocks.

For this equation, the dummy variable indicates that during 1994-2002 *lny* was slightly higher than during 1985-1993 (before the first South African democratic election) and 2003-2019 (four years after the first South African democratic election to date), ceteris paribus.

Table 4 *– ARDL Model results: Equation 6 and 7*

Dependent Variable: *lny*			Dependent Variable: *MM*		
Period	1985-2019		Period	1985-2019	
Independent Variables	Coefficient	p-value	Independent Variables	Coefficient	p-value
MM	3.17E-05***	0.0001	*lny*	23794.170***	0.0006
lnk	0.214***	0.0000	*lnk*	-5328.172***	0.0007
lnto	-0.265***	0.0000	*lnto*	6558.180***	0.0019
d	0.032***	0.0069	*d*	-1023.757***	0.0004
ARDL F-stat	**9.30**		**ARDL F-stat**	**15.41**	
Upper bound CV (1%)	5.72		Upper bound CV (1%)	5.72	
Lower bound CV (1%)	4.4		Lower bound CV (1%)	4.4	
Cointegration conclusion	Cointegration		Cointegration conclusion	Cointegration	
Upper bound CV (5%)	4.57		Upper bound CV (5%)	4.57	
Lower bound CV (5%)	3.47		Lower bound CV (5%)	3.47	
Cointegration conclusion	Cointegration		Cointegration conclusion	Cointegration	
Upper bound CV (10%)	4.06		Upper bound CV (10%)	4.06	
Lower bound CV (10%)	3.03		Lower bound CV (10%)	3.03	
Cointegration conclusion	Cointegration		Cointegration conclusion	Cointegration	

(*/**/***) Statistically significant at a (10/5/1)% level

Note: *Results of Eq 8 and 9 in the Appendix are not in the focus of this paper.*

The ΔMMt ARDL (3, 4, 4, 3, 2) model shows that in the long run, a 1% increase in lny increases the MM by 237.94 units, ceteris paribus. That is, the surplus of electricity becomes more expansive as the economy grows. Conversely, a 1% increase in k significantly decreases MM by 53.28 units if all else is constant. This decrease in the surplus of electricity enjoyed per person could occur from the electricity consumption levels rising faster than the electricity supply level rises when Capital is accumulated. Thus, the surplus, and hence the mismatch, would be reduced through this channel. A 1% increase in *lnto* causes a 65.58-unit increase in *MM*, ceteris paribus. The dummy variable, *d*, is added to this model to account for the volatility in the mismatch between 1994 and 2002. Compared to 1985-1993 and

2002-2019, the mismatch was more negative (indicating a shortage in the electricity market) from 1994 to 2002, ceteris paribus. This result is, in part, due to Eskom's governance issues during this time.

***Figure 3** – ARDL model residual analysis*

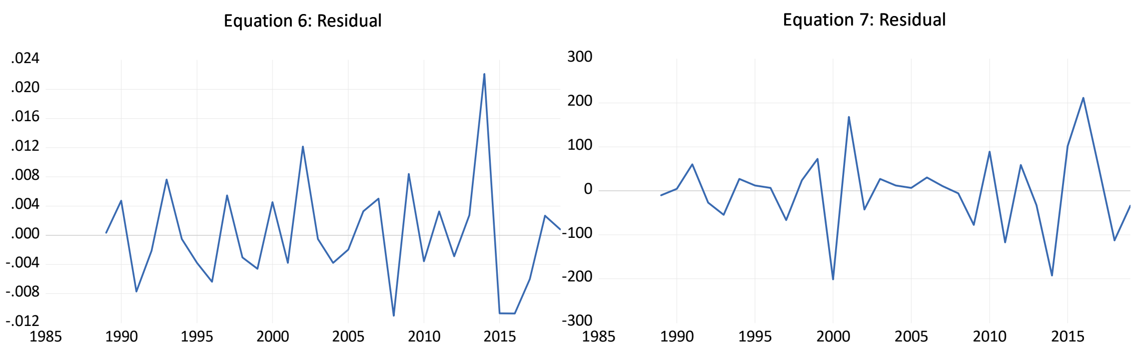


Table 5

Dependent variable of residual	Skewness	Kurtosis	Jacque-Bera stat	Jacque-Bera Prob.	LM test F-stat	LM test Prob.
Δlny_t	0.882	4.474	6.828	0.033	0.840	0.3834
ΔMm_t	-0.123	3.732	0.770	0.680	1.669	0.256

The diagnostics for the model residuals indicate the essential requirements for the validity of an ARDL model. The residuals of both Equation 6 and 7 are typically distributed. They exhibit no serial correlation, confirmed by the graphical analysis of these two residuals shows a relatively zero-mean reverting process for the residuals of both equations. The AIC prescribes 0 lags for the residual of Δlny_t (equation 6) and 2 lags for the residual of ΔMm_t (equation 7) as the optimal lag lengths for the LM tests of these residuals. The results presented in Figure 3 show that the null hypothesis of no serial correlation cannot be rejected for both equation's residuals. Δlny_t's residual is expected at a 1% level of significance. ΔMm_t's residual is normally distributed at a 1%, 5% and 10% significance level. The residual diagnostics are confirmed by the graphs of the residuals of Equations 6 and 7. Hence, the conclusions made from the inference of the ARDL model are statistically reliable.

6. Conclusion and Discussion

This paper primarily sought to determine the nature of the long-run relationship between the mismatch of electricity supply and demand and economic growth between 1985 and 2019 for the South African case. The literature examining the interaction between the electricity market and economic growth has predominantly focused on either analysing electricity consumption's relationship with economic growth or electricity supply's relationship with economic growth. This paper uses electricity supply and consumption to account for the electricity market's "mismatch" variable. This mismatch's relationship with economic growth is then examined throughout this paper. The ARDL analysis shows evidence of co-integration amongst economic growth, the electricity mismatch, capital accumulation and trade openness, all per person employed.

The main findings indicate, first, the fact that a rising surplus of electricity enhances economic growth for the South African case. This paper's second main finding is that increasing economic growth is a significant contributor to the rise in South Africa's electricity surplus. These findings are at odds with this paper's initial hypothesis that any inefficiency (shortage or surplus) in the electricity market ought to be adverse for economic growth. This outcome that a rising rest in the electricity market bolsters economic growth is easily reconcilable in the long run. This finding seems relatively intuitive. When the economy grows, this facilitates the rise in electricity supply relative to electricity consumption. The most obvious explanation for this lies in the fact that a growing economy creates room for increasing electricity generating capacity and, thus, potentially, space for a more significant surplus.

Similarly, ceteris paribus, when electricity supply increasingly exceeds electricity consumption, enhances economic growth. This fact means that when the consumption of electricity rises, it must be met with a sufficiently rising electricity supply for the electricity market to maintain an increasing surplus. In this way, the rising mismatch causes economic growth, and increased economic growth causes a rise in the mismatch in the long run. Therefore, the challenge does not lie only in increasing the supply of electricity but in maintaining an increase in the demand for electricity at a conducive level for economic growth. This challenge calls for the close monitoring of these electricity market indicators (electricity supply and demand). Ultimately, this paper calls for the economy's expansion to coexist with the positive development of the mismatch in the electricity sector in the long run.

As mentioned in Section 3, the electricity surplus from about 2003 (seen in Figure 1) has not resulted in this excess electricity supplied being consumed by households and businesses. In fact, despite this surplus, load-shedding has increased through the electricity market. Therefore, this excess electricity supply is probably held by independent power producers who are not mandated to provide household and business electricity. This notwithstanding, an excess supply of electricity (even one that does not aid directly households and businesses) is conducive for economic growth. Therefore, this paper would suggest that alleviating shortages in Eskom's electricity supply and consumption mismatch and then ensuring that this enterprise maintains a sustained surplus would benefit growth.

A short run analysis is not done because of the tendency of electricity supply, a component of the mismatch, data to adjust in the long run rather than in the short run. Thus, a finding which advocates for a short run policy implementation would not enrich this particular study. As such, this detailed long-run analysis is apt for the variables in this study.

The findings of this paper highlight the potential damage to the economy that a shortage of electricity supply relative to electricity demand could have. This finding is particularly topical for the South African case, given the persistence of load-shedding since 2007 (Council for Scientific and Industrial Research, 2019). According to this paper's findings, the mismatch is conducive for growth only when the supply of electricity exceeds the electricity demand. Load-shedding occurs when there is not enough electricity to meet the amount of electricity demand in the market. Thus, load-shedding and other such electricity shortages undermine the potential for the electricity market to affect the South African economy in the long run positively.

Furthermore, Eskom's ageing coal power plants threaten electricity supply security in South Africa (du Venage, 2020). Eskom is reportedly managing a power plant system with an average age of 37 years (Mabuza, 2019). The implication is that Eskom often encounters unplanned maintenance costs, which, in turn, delay planned maintenance projects and thus, render the Eskom power plant system in its entirety unreliable (Mabuza, 2019). Hence, the president of South Africa's announcement for the allowance of independent power producers to serve the electricity demand needs of municipalities will likely translate to a positive outcome for the long-run trajectory of the South African economy (Republic of South Africa, 2020).

Policies that support bolstering economic growth and electricity supply relative to electricity consumption growth, in the long run, are supported by the findings of this paper. The onus that rests on policymakers is ensuring that electricity demand can rise enough to facilitate economic growth while ensuring that electricity supply surpasses this rising demand. Perhaps, an interesting avenue for future research to make this policy recommendation more specific is to study which electricity generation sources are the most efficient to increase electricity supply in the long run without hampering electricity consumption. Furthermore, it might be interesting to examine the limits of this surplus. Mainly, a study examining the optimal mismatch level would be valuable for providing more specified policy recommendations.

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8. Appendix

Table A *– Phillips-Perron (PP) Stationarity tests*

Series	*Model*	*Phillips-Perron (PP)*	
		Bandwidth	*PP*
lny	*Trend & intercept*	*3*	*-2.138*
	Intercept	*4*	*-1.500*
	None	*7*	*1.054*
Δlny	*Trend & intercept*	*10*	*-4.063***
	Intercept	*11*	*-4.192****
	None	*10*	*-4.095****
Mm	*Trend & intercept*	*0*	*-2.496*
	Intercept	*0*	*-1.923*
	None	*1*	*-2.029***
$\Delta\ Mm$	*Trend & intercept*	*4*	*-5.571****
	Intercept	*4*	*-5.673****
	None	*4*	*-5.718****
lnk	*Trend & intercept*	*0*	*-2.172*
	Intercept	*3*	*-0.905*
	None	*4*	*0.884*
Δlnk	*Trend & intercept*	*3*	*-5.055****
	Intercept	*2*	*-5.108****
	None	*1*	*-4.100****
lnt	*Trend & intercept*	*14*	*-1.513*
	Intercept	*3*	*-0.580*
	None	*5*	*0.552*
$\Delta lnto$	*Trend & intercept*	*26*	*-7.488****
	Intercept	*6*	*-4.900****
	None	*5*	*-4.957****

(*/**/***)   Statistically significant at a (10/5/1)% level

Table B *- ARDL Model results: Equation 8 and 9*

Dependent Variable: *lnk*			Dependent Variable: *lnto*		
Period	1985-2019		Period	1985-2019	
Independent Variables	Coefficient	p-value	Independent Variables	Coefficient	p-value
lny	1.595	0.1434	*lny*	-5.625***	0.0083
MM	0.0002	0.1012	*MM*	0.0002**	0.0152
lnto	1.228**	0.0107	*lnk*	1.302***	0.0098
d	-0.021	0.8163	*d*	0.171**	0.0115
ARDL F-stat	**6.02**		**ARDL F-stat**	**4.462**	
Upper bound CV (1%)	5.72		Upper bound CV (1%)	5.72	
Lower bound CV (1%)	4.4		Lower bound CV (1%)	4.4	
Cointegration conclusion	Cointegration		Cointegration conclusion	Inconclusive	
Upper bound CV (5%)	4.57		Upper bound CV (5%)	4.57	
Lower bound CV (5%)	3.47		Lower bound CV (5%)	3.47	
Cointegration conclusion	Cointegration		Cointegration conclusion	Inconclusive	
Upper bound CV (10%)	4.06		Upper bound CV (10%)	4.06	
Lower bound CV (10%)	3.03		Lower bound CV (10%)	3.03	
Cointegration conclusion	Cointegration		Cointegration conclusion	Cointegration	

(*/**/***) Statistically significant at a (10/5/1)% level