Relationship between energy consumption and economic growth in South Africa: Evidence from the bootstrap rolling-window approach

Janneke Dlamini
Department of Economics, University of Pretoria
Pretoria, 0002, SOUTH AFRICA

Mehmet Balcilar
Department of Economics, Eastern Mediterranean University
Famagusta, NORTHERN CYPRUS,
via Mersin 10, TURKEY
Rangan Gupta

Department of Economics, University of Pretoria
Pretoria, 0002, SOUTH AFRICA
Email: rangan.gupta@up.ac.za

Roula Inglesi-Lotz
Department of Economics, University of Pretoria
Pretoria, 0002, SOUTH AFRICA

ABSTRACT

This article examines the relationship between energy consumption (EC) and economic growth for South Africa for the period 1971–2009. Most studies examining this relationship do assume that it remains constant through the years; however, the reality might be different since many factors can affect the existence and direction of this causality. This article looks at a bivariate vector autoregressive process and takes into consideration any instability in the model using bootstrap rolling Granger non-causality tests. Full-sample Granger causality tests report no causal relationship between the two variables. Moreover, parameter stability tests detect instability in the model which means that the full-sample Granger causality results are not valid. We therefore allow for the possibility of structural breaks by using bootstrap rolling-window Granger causality tests. Although our results are not very strong, we do however find a sub-period from 1987 to 1989 where EC has a causal effect on gross domestic product growth. Except for this brief sub-period, the results show no linkage between economic growth and EC.

JEL Codes: C32, Q43, Q48

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INTRODUCTION

Many studies in the energy-growth literature mainly seek to find a single relationship between energy and economic growth for a specific time period and ignore how this relationship has evolved over the years. No consensus has been reached as far as discovering what the exact relationship is between energy consumption and growth as studies have produced contradictory results. Esso (2010) attributes the mixed results about this relationship to the heterogeneity in climate conditions, the level of development a country has reached, different methodologies employed, omitted variable bias and the time horizons of studies. A shortcoming of the energy-growth literature is the assumption that energy and economic growth maintain the same relationship over time and one way to overcome this single relationship between energy and growth is to account for structural breaks (Gross, 2012). Fallahi (2011) notes that many studies investigate the causality relationship between energy and GDP with the assumption that the parameters in their models are constant over a sample period indicative of a stable relationship which is not the case, as the world has experienced a few crises including the energy crisis in the past decades.

The purpose of the study is to investigate whether a relationship between energy consumption and economic growth exists and in which direction the causal relationship flows for South Africa in the period from 1971 to 2009. The paper makes use of bootstrap and rolling-window methodology employed by Balcilar *et al.*, (2010). By using this method, not only are we able to detect existence and direction of causality in a time-varying fashion but also detect whether any structural shifts occurred over the sample period.

Causality between energy consumption and economic growth have been classified into four hypothesis; growth, conservative, feedback and the neutrality hypotheses. The conservation hypothesis is of the view that GDP is the driving force behind energy consumption growth. On the other hand the growth hypothesis shows unidirectional causality from energy consumption to economic growth indicating that energy consumption has predictive power over GDP growth. The feedback hypothesis is indicative of a two way relationship between energy consumption and economic growth and implies unidirectional causality from energy consumption to economic growth and also unidirectional causality from economic growth to energy consumption. The non-existence of a relationship between energy consumption and growth is known as the neutrality hypothesis and means that neither economic growth nor energy consumption has predictive power for each other.

The implications of all four hypotheses are important for policy makers to formulate appropriate energy policies. If unidirectional causality exists from income (economic growth) to energy consumption then it may be said that energy saving policies can be implemented with adverse effects on the economy (Asufu-Adjaye, 2000). However, if unidirectional causality runs in the opposite direction, from energy consumption to economic growth, reducing energy (energy conservation policies) tends to reduce output growth and thus these policies may hamper the growth of the economy (Alam *et al.*,2012). For causality running in a two way direction, from energy consumption and vice versa, energy use and GDP are interdependent and where no causal relationship is found, economic growth and energy policies are deemed independent of each other (Akkemik and Göksal, 2012).

The literature on the energy-GDP link in South Africa is not very extensive and is mixed with no consensus being reached on the direction of causal relationship.[1] Inglesi-Lotz and Pouris (forthcoming) observe that most studies in South Africa employ a multivariate analysis which makes it difficult to compare studies as various variables are included in the models. Odhiambo (2010) examines the relationship between energy consumption and economic growth for South Africa, Kenya and Congo (DRC) for the period 1972-2006. For South Africa, they find unidirectional causality flowing from energy consumption to economic growth in both the long and the short run. For South Africa, this implies that the country is energy dependent and therefore should seek more efficient and cost effective sources of energy to handle rising energy demand especially in the short run. Esso (2010) examines the causal relationship between energy and growth for seven African from 1970-2007 and does not find any causal link between energy consumption and GDP for South Africa in the long

[1] See Inglesi-Lotz and Pouris (forthcoming) for studies on causality of energy and electricity demand in South Africa.

run. However, short-run unidirectional causality from economic growth to energy consumption is found. The causality result implies that energy conservation or expansion polices in the long term will have no effect on economic growth as the two variables are independent of each other.

Menyah and Wolde-Rufael (2010) use the bounds testing approach in investigating the relationship between energy consumption, pollutant emissions and economic growth for the sample period from 1965-2006 in South Africa. They include labour and capital in their multivariate framework and find that energy consumption has predictive power for GDP growth. Similarly, Wolde-Rufael (2009) examines the same relationship for seventeen African countries using Toda and Yamamoto Granger causality approach and finds the same unidirectional relationship from energy use to growth for South Africa for the period 1971-2004. These studies support the growth hypothesis implying that energy conservation policies will have an adverse effect on the economic growth of the country as energy plays an important role in the growth prospects of the country. Other studies that look at this relationship for South Africa include Ziramba (2009) who measures the relationship between disaggregate forms of energy consumption and industrial production carried out using the Toda and Yamamoto Granger causality technique and Kahsai *et al.*,(2012) for Sub-Saharan countries using panel cointegration approach. The time spans of the studies are 1980-2005 and 1980-2007, respectively. Ziramba (2009) results indicate a bidirectional causal link between industrial production and oil consumption with absence of causality for the other sources of energy namely coal and electricity. Therefore increased oil production may require more oil resources while more oil resources may lead to increased industrial production. On the other hand, results found by Kahsai *et al.*, (2012) support the neutrality hypothesis in the short-run but the feedback hypothesis in the long-run.

Most studies investigate full-sample Granger causality and often do not investigate the possibility of structural breaks in the model. The novelty in our paper is that we employ a bivariate model and use time-varying rolling bootstrap causality techniques which test Granger causality on rolling sub-samples with a 15 year fixed window which capture any structural breaks in the model. By using this approach, we are able to examine the energy consumption- GDP relationship as it evolves in time. To the best of our knowledge, this is the first study to examine the relationship between the growth rates of per capita energy consumption and per capita GDP using a time-varying bootstrap rolling-window approach for South Africa.

The remainder of the paper is organised as follows. Section 2 and 3 discuss the econometric approach and empirical results, respectively. In section 4, the conclusion is presented and policy recommendations are given.

2. METHODOLOGY

2.1 Econometric Model

Analogous to Balcilar *et al*., (2010) who investigate the relationship between energy consumption and economic growth using bootstrap Granger non-causality tests with fixed-size rolling sub-samples, we employ the same technique. We use the Likelihood ratio and Wald test statistics to carry out the Granger causality tests. Engle and Granger (1987) demonstrate that if past values of a time series*(X)* in conjunction with past values of a second time series*(Y)* can better improve the prediction of future values of time series*(Y)*, then it can be said that time series *(X)* Granger causes time series *(Y)*.Standard Granger causality tests are unfavourable as they a produce non-standard asymptotic distribution and therefore we employ the Toda and Yamamoto(1995) modified Granger non-causality tests to the bivariate

VAR model on rolling sub-samples with a 15 year fixed-size window. The Toda and Yamamoto procedure overcomes issues associated with spurious regression as it can be employed regardless of whether variables are integrated of any order or cointegrated whilst maintaining valid asymptotic properties. Another issue with standard Granger causality tests is that they may cause specification bias and non-asymptotic critical values especially when dealing with a small sample. We therefore turn to the residual based (RB) bootstrapping technique which guards against pre-testing bias and provide robust critical values when testing for Granger causality. This method is demonstrated by Shukur and Mantalos (1997a, 1997b); Mantalos and Shukur (1998); Shukur and Mantalos (2000) and Mantalos (2000).

We test for the stationarity of energy consumption and economic growth using the augmented Dickey Fuller, Phillips and Perron (1988) and Ng and Perron (2001) tests. The Akaike Information Criterion selects the appropriate lag length to test for stationarity. Furthermore, we investigate the existence of a long run relationship between the two variables. Detection of a cointegrating relationship signifies the existence of causality in at least one direction (Granger, 1987). Cointegration is tested using the Johansen (1991) maximum likelihood test.

We perform bootstrap Granger causality tests on both the full-sample and rolling sub-samples. However, to validate our full-sample Granger causality results, we must test for the stability of the model. Usual Granger causality tests show sensitivity to sample period changes which may be the reason why some studies find causality between energy consumption and GDP and others do not (Balcilar *et al.*, 2010). We investigate parameter constancy in order to analyse the behaviour of parameter estimates over time. Often, structural changes in the economy can result in instability of parameters and therefore cast doubt on the reliability of full-sample causality results. We employ the *Sup-F*, *Exp-F* and *Mean-F* tests for stability. The *Sup-F* tests for an abrupt shift in the parameter values whilst the *Exp-F* and *Mean-F* tests consider whether parameters are stable over time. The detection of instability in our model implies that we cannot rely on full-sample Granger causality and this motivates the application of rolling regressions to our Granger causality tests. The rolling-window Granger causality tests allow us to identify any structural breaks in the model as the sub-samples roll over time. Additionally, we are able to detect different causal relationships evolving over time which is of significance in this paper.

The bivariate VAR model representation is as follows:

$$y_t = \Phi_0 + \Phi_1 y_{t-1} + \cdots + \Phi_p y_{t-p} + \varepsilon_t \qquad \mathrm{t} = 1,2,...,\mathrm{T} \tag{1}$$

Where $\varepsilon_t = (\varepsilon_{1t}, \varepsilon_{2t})'$ is a white noise process with zero mean and covariance matrix $\sum$. The lag order p is determined by the Akaike Information Criterion. In order to simplify the representation Balcilar *et al.*,(2010) partition y_t into two subvectors, y_{1t} and y_{2t}, representing electricity consumption and GDP respectively and write equation (1) in the following compact form

$$y_t = \begin{bmatrix} y_{1t} \\ y_{2t} \end{bmatrix} = \begin{bmatrix} \phi_{10} \\ \phi_{20} \end{bmatrix} + \begin{bmatrix} \phi_{11}(L) & \phi_{12}(L) \\ \phi_{21}(L) & \phi_{22}(L) \end{bmatrix} \begin{bmatrix} y_{1t} \\ y_{2t} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix} \tag{2}$$

Where $\phi_{ij}(L) = \sum_{k=1}^{p} \phi_{ij,k} L^k, i, j = 1,2$ and the lag operator is defined as $L^k x_t = x_{t-k}$.

We can test the hypothesis that GDP does not granger cause electricity consumption by imposing the zero restriction $\phi_{12,i} = 0$. In a similar manner, we can test the null hypothesis that electricity consumption does not granger cause GDP with the restriction $\phi_{21,i} = 0$ for $i = 1,\cdots, p$.

2.2 Data

Annual aggregate data were utilized in the study. The variables used to form our bivariate model are real GDP per capita (GDP) measured in millions of Rand in constant 2005 prices and real energy consumption (EC)measured in kilograms of oil per capita. The sample selected ranges from 1971-2009 and both variables are converted into natural logarithm which effectively means that our sample begins in 1972. The data is collected from the World Development Indicators (WDI) maintained by the World Bank.

4. EMPIRICAL RESULTS

The unit root tests employed are based on three regressions; one that includes a constant, another that includes a trend and a constant and lastly a regression without a trend or a constant. Using the ADF (1981) test, the Z_{α} test of Phillip and Perron (1988) and the MZ_{α} test of Ng-Perron (2001), we tested for unit root and established that our variables, EC and GDP, are non-stationary in levels. However, differencing the variables once showed the variables to be stationary *I(1)*. Two *I(1)* series are said to be cointegrated if there exists a linear combination of them that is *I(0)*. Since the two variables are integrated of the same order we test for cointegration. To investigates whether our variables are cointegrated or not we used the Johansen (1991) maximum likelihood test. The optimal lag length selected by the Akaike selection criterion for the VAR with variables in growth rates is one. The results from the Johansen test show test statistics that have values less than the critical values at a 5 percent level of significance and therefore we conclude that no cointegration exists between energy consumption and economic growth[2]. Finding a long-run relationship between energy consumption and economic growth would imply the use of a vector error correction model (VECM) in causality testing, however, we use a VAR in first difference as no cointegration could be detected..

[2]Results of unit root tests and Johansen (1991) maximum likelihood test for cointegration are available from authors upon request.

We test for full-sample Granger causality in the short-run using bootstrap likelihood ratio and bootstrap Wald test statistics. The results reported in **Table 1**show that we cannot reject the null hypothesis that energy consumption does not Granger cause GDP and we cannot reject the null hypothesis that GDP does not Granger cause Energy consumption at a 5 percent level of significance. This signifies that both energy consumption and GDP are interdependent of each other and therefore do not have a causal effect on one another.

Table 1: Full-Sample Granger Causality Tests

	H_0: Energy Consumption does not Granger cause GDP		**H_0: GDP does not Granger cause Energy Consumption**	
	Statistics	***p*-value**	**Statistics**	***p*-value**
Bootstrap *LR* Test	1.114	0.310	0.285	0.598
Bootstrap Wald Test	1.135	0.310	0.286	0.598

Most studies base their findings on VAR models like the one in equation (1) but never examine the stability of the estimates (Balcilar *et al.*,2010) and therefore we cannot simply accept the above result without validating whether the model is in fact stable or not. If parameter estimates are found to be instable then we cannot rely on the full-sample Granger causality findings. The *Sup-F*, *Exp-F* and *Mean-F* tests are used to analyse the stability of the system and have the null hypothesis of parameter constancy against the alternative hypothesis of non-constant parameters. We follow Andrews (1993) by trimming off 15 percent of the ends of all three stability tests and therefore run the stability tests only on [0.15. 0.85] of the sample. The results of the stability tests are presented in **Table 2**.

Table 2: Parameter Stability Tests in *VAR* (1) Model

	Energy Consumption Equation		GDP Equation		*VAR*(1) System	
	Statistics	Bootstrap *p*-value[a]	Statistics	Bootstrap *p*-value	Statistics	Bootstrap *p*-value
Mean-F	7.59**	0.02	7.52**	0.02	7.27	0.25
Exp-F	43.57	1.00	16.00***	<0.01	7.68**	0.03
Sup-F	93.80***	<0.01	38.66***	<0.01	21.39**	0.03

Notes: *, ** and *** indicates significance at 10, 5 and 1 percent, respectively

[a]p-values are obtained with 2000 replicates

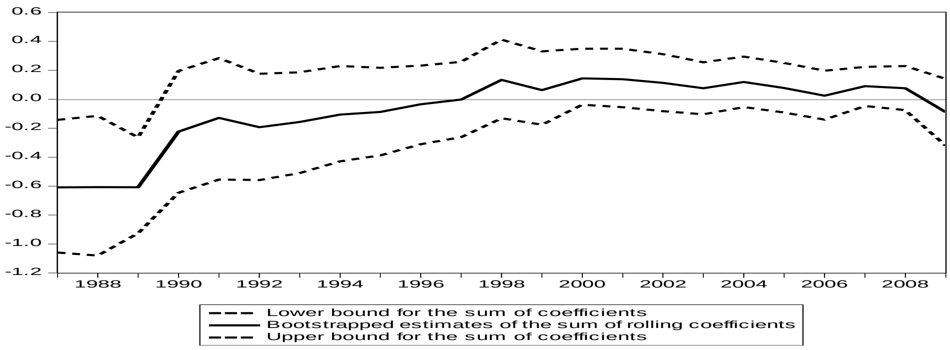
In the energy equation both the *Mean-F* and *Sup-F* have bootstrap *p*-values that are less than 0.05 indicating rejection of the null hypothesis of parameter constancy at a 5 percent level of significance resulting in instability of the energy equation. On the other hand, all three stability tests in the GDP equation suggest that parameters are not constant thereby we can reject the null hypothesis at a 5 percent significance level. The VAR (1) system has instable parameters indicated by the Exp-F and Sup-F tests but the Mean-F test fails to reject the null hypothesis of constant parameters. To sum up the stability tests, we find instability in the GDP and energy equation as well as in the system as a whole which shows that there may have been some structural shifts that affected the variables and system as a whole.

The instability in our model gives us enough reason to use rolling regressions in investigating causality and enables us to identify structural breaks as the system evolves in time and possibly link the structural shifts in different sub-samples to significant economic events that could have impacted the economy. In this type of regression we specify a window size and roll each sub-sample removing the initial observation in the beginning of the sub-sample and adding one observation at the end of the sub-sample. Following Balcilar *et al.*, (2010), our window size, *l*, is fixed at 15 years which means that we have a series of 23 sub-samples. According to Balcilar *et al.*, (2010), a large window size reduces the number of estimates and a smaller window size leads to bigger variance in estimates attributed to the reduced heterogeneity. We use the bootstrapping technique with rolling-window Granger causality tests as it tends to produce more precision in estimates. Using the bootstrap rolling-window approach to Granger causality, we test the null hypotheses that energy consumption does not Granger cause GDP and GDP does not Granger cause energy consumption. Bootstrap *p*-values are calculated, plotted and their variation is examined.

The VAR model in equation (2) is used to roll through the sample period from 1972-2009, $t = \tau - 14, \tau - 13, ..., \tau, \tau - 15, ..., T$ and the *p*-values of the LR statistic are calculated using the RB method. We also compute the magnitude of the impact of GDP on energy consumption and the magnitude of the impact of energy consumption on GDP as done in the Balcilar (2010) paper. $N_b^{-1} \sum_{k=1}^{p} \hat{\phi}^*_{21,k}$ and $N_b^{-1} \sum_{k=1}^{p} \hat{\phi}^*_{12,k}$ represent the mean of all bootstrap estimates which evaluate the impact of GDP on energy consumption and vice versa, respectively, where N_b is the number of bootstrap repetitions and $\hat{\phi}^*_{21,k}$ and $\hat{\phi}^*_{12,k}$ are the bootstrap least squares estimates for our VAR. We use 90 percent confidence intervals, where the lower and upper bound equals to the 5th and 95th quantiles of each $\hat{\phi}^*_{21,k}$ and $\hat{\phi}^*_{12,k}$, respectively.

FIGURE 1

(a) Bootstrap *p*-values testing the null hypothesis that EC does not Granger cause GDP



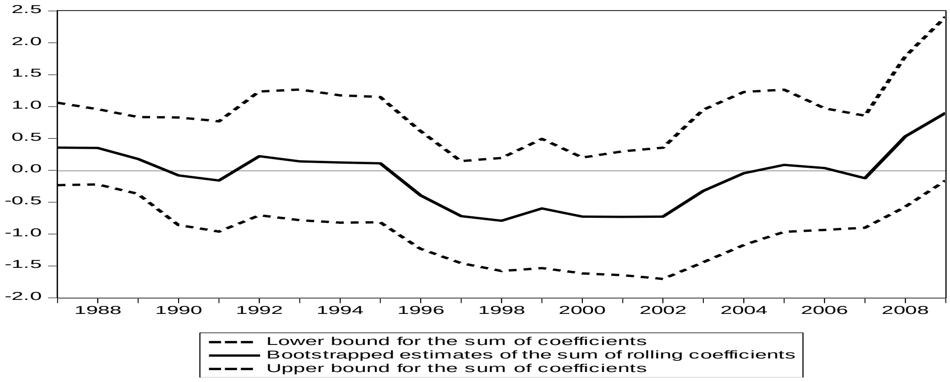
(b) Bootstrap estimate for the sum of the rolling coefficients for the impact of EC on GDP

In **Figure 1** above, we show two **panels (a)** and **(b)** representing the bootstrap *p*-values for the null hypothesis EC does not Granger cause GDP and the magnitude of impact of EC on GDP. In **Panel (a)** we reject the null hypothesis during the period 1987-1989 at a 10 percent significance level and conclude that EC had predictive power for GDP during this period. However, we fail to reject the null hypothesis that EC does not Granger cause GDP for the rest of the sample. **Panel (b)** in **Figure 1** shows that EC has negative predictive power for GDP during the 1987-1989 sub-period, however, it is statistically significant.

On the other hand, **Panel (a)** and **(b)** of **Figure 2**show bootstrap *p*-values testing the null hypothesis that GDP does not Granger cause EC and the magnitude of the impact of GDP on EC, respectively. From **Panel (a)** we cannot reject the null hypothesis for the entire sample meaning that GDP has no impact on EC. In **Panel (b)**, the sign of the impact of GDP on EC is mostly negative during the sample but is statistically insignificant.

FIGURE 2

(a) Bootstrap p-values testing the null hypothesis that GDP does not Granger cause EC



(b) Bootstrap estimate of the sum of the rolling coefficients for the impact of GDP on EC

The results show similarity to our full-sample Granger causality results in Table 1. Our results are also supported by studies of Esso (2010) and Kahsai *et al.*, (2012) who found no relationship between energy consumption and GDP in South Africa. Although we find unidirectional causality from EC to GDP, this result is however quite weak, as for most of the sample period considered, no causality existed in either direction indicative of the neutrality hypothesis. Nevertheless, it is important to investigate structural changes when performing causality analysis because this may be a key factor in determining the causality result.

Furthermore, the rolling regression that we use in conjunction with Granger causality tests enabled us to detect any substantial changes in parameter values hence pointing out structural breaks as the model evolved over time.

5. Conclusion

The paper investigates the causal relationship between per capita energy consumption and per capita GDP growth for sample period from 1971-2009 for South Africa. We do this by using a bootstrap rolling-window approach to Granger causality which takes into consideration the structural breaks in the model and also conducts causality test in a time-varying manner. The study employed a bivariate VAR with no additional variables included which is uncommon in many South African studies. When additional variables are included, this tends to cloud the true causality direction as it is may be possible that these additional variables have some influence on the variables which are actually being tested for a causal relationship. Hence, having additional variables in the model might result in wrong inferences concluded about the causal relationship.

Preceding estimation, we test our variables for unit root as well as for a long-run relationship. The results indicate that the variables have to be differenced once before becoming stationary and therefore are *I(1).* No cointegration is established between energy consumption and economic growth and therefore estimation is carried out using a VAR in first difference. As done in most studies, we tests for Granger non-causality on the full-sample. However, we use bootstrap Granger causality which guard against small samples and our results support the neutrality hypothesis showing no causal link between energy consumption and GDP. The validity of the full-sample results is based on whether our model is exhibits stability or not. We find that there exist structural breaks (instability) in our energy consumption and GDP equations as well as in the *VAR (1)* system. Consequently, we cannot rely on the full-sample Granger causality results and thereby use bootstrap rolling-window Granger causality tests with a 15 year window size. The results from this test indicate a brief sub- period from 1987-1989 where unidirectional causality flowing from energy consumption to GDP was found Moreover, no evidence in favour of causality in the opposite direction is found.

It is of importance in this study to link causality relationships to significant economic events that may have resulted in a causal relationship flowing in a certain direction. During the 1981-1986 periods, the world experienced a substantial decrease in the price of oil also known as ‘the great price collapse’ which was due to the Iran and Iraq conflicts and led to a fall in oil production (Hamilton, 2011). Subsequently, South Africa experienced increases in Brent crude oil prices in 1987 and in 1989. The price of oil increased from $17.84 in 1986 to $19.65 in 1987 and also in 1988-1989 from $15 to $18.03 (SARB, www.resbank.co.za). This period coincides with the sub-period in our sample where unidirectional causality flowing from EC to GDP is found. The increase in price level may help explain the negative causality relationship that is seen in **Panel (b)** of **Figure 2**.

The evidence affirming causality from energy consumption to GDP is not large but it does illustrates the importance of investigating models for instability and investigating Granger causality in a time-varying fashion. Investigating Granger causality in a time-varying manner enables us to detect different causal relationships in different sub-samples. The implication this has for policy makers is that they cannot rely on full-sample Granger causality test without investigating structural shifts and must formulate appropriate policies for differing time periods as new data on energy consumption and GDP becomes available. Policy makers have the task of designing new policies after having identified significant economic events that may have had an impact on the direction and sign of the causal relationship. This they can do by carrying out causality analysis in a time-varying approach.

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