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Natural gas consumption and economic growth: evidence from selected natural gas vehicle markets in Europe

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Abstract

In this study, the relationship between natural gas consumption (NGC) and economic growth is examined. Twelve (12) countries in Europe are considered, 10 of which make up the top natural gas vehicle (NGV) markets in Europe. The study considers four main variables in this exercise, namely; gross fixed capital formation, labour force, trade openness, and real GDP. It makes use of panel cointegration analysis and long-run vector error correction model analysis in assessing both the short-run and the long-run relationship dynamics between NGC and economic growth. The results show that a long-run impact of NGC on economic growth does indeed exist. In the short run, however, this does not seem to be the case. The results also suggest the existence of the growth hypothesis in Austria, Bulgaria and Switzerland, while the United Kingdom (UK) and Italy support the conservation hypothesis.

Keywords: natural gas consumption; economic growth; panel data analysis; natural gas vehicle markets

1 Introduction

Alternative sources of clean and efficient energy, and their uptake across the globe, have been the subject of much discourse in both academic and economic policy environments over the past few

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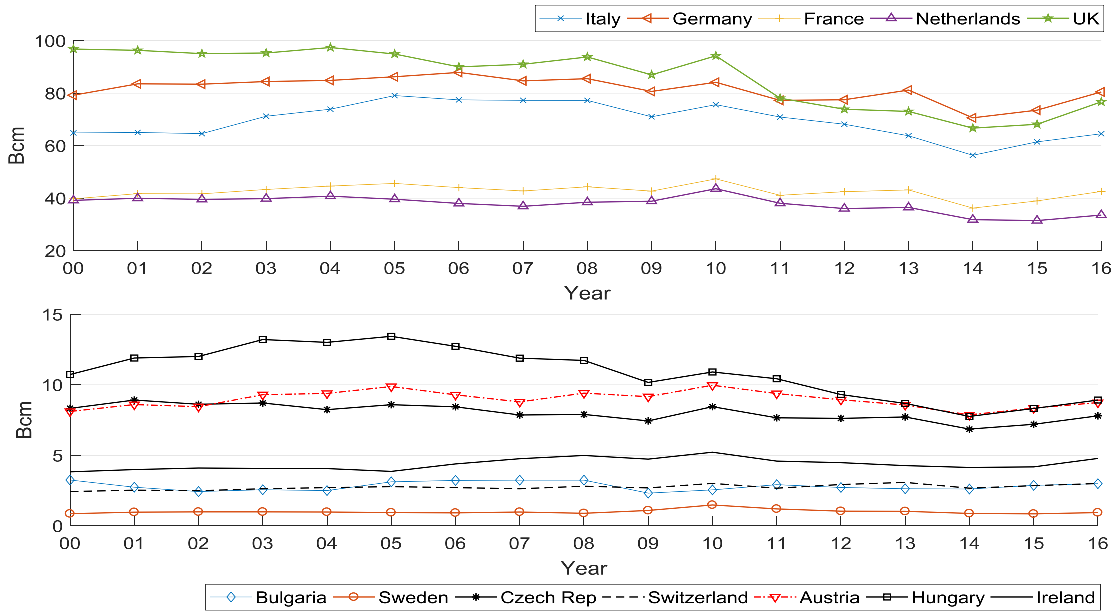
years. This is due to the increasing urgency of energy demands to sustain economic activities and growth, and the resultant impact on the environment. In this quest, natural gas as an alternative source of energy has steadily increased across Europe over the past two decades. However, the uptake has differed significantly across countries, with the consumption rate further being affected differently after the 2007 global crisis (see Figure 1). This leads to the question of how the usage of gas-based energy has proliferated Europe over the past two decades and what the dynamics of such consumption is in relation to economic growth, especially for its largest consumers.

In 1991, total natural gas[2] consumption globally was at 1 034 billion cubic metres (bcm), which had grown to about 3 543 bcm by 2016. Of the 1 034 bcm in 1991, Europe accounted for 33% of the gas consumption (at 341 bcm), but over the 15-year period since then, NGC has increased to about 429 bcm, while the total percentage share has fallen to 12% [1]. Moreover, the European Union (EU) reported a 7% growth rate for 2016 but a –2% growth rate per annum for 2005 to 2015. A question that comes to mind is what dynamics may be at play and if any growth effects are at work. In comparison to traditional sources of energy such as oil (petrol and diesel), NG is more environmentally friendly. Additionally, substitution of these energy sources with NG would help drive countries closer toward the goals set by some of the most recent climate change agreements, such as the Kyoto Protocol and the Paris Agreement[3].

[2] The NG excludes gas converted to liquid fuel but includes derivatives of coal and NG consumed in gas-to-liquids transformation.

[3] Some studies have argued that NG may not be as great an alternative to helping curb CO2 emissions. This is because previous measures of methane emissions have not been as accurate, and actual measures may be quite detrimental to emissions levels (see Karion et al. [2. Karion, A., et al., *Methane emissions estimate from airborne measurements over a western United States natural gas field.* Geophysical Research Letters, 2013. **40**(16): p. 4393-4397.[3]).

Figure 1: NGC for the top 10 European NGV markets, Ireland, and the UK



This paper piggybacks on the "energy-growth" discourse originally introduced in the seminal paper by [3], which explores the potential feedback effect of policies aimed at cutting down energy consumption, and how such policies impact income levels vis-a-vis different types of energy sources. Whereas energy related policy recommendations need to be backed by a proper understanding of the potential impact of reducing (or increasing) different types of energy sources (including gas), on the income level. In theory, natural gas can be thought of as an alternative/substitute to some of the already existing inputs in a country's production function. Given the potential ills of fossil fuels, we think of natural gas as a more environmental friendly alternative, owing to its lower carbon component. Thus, there is a need to examine the significance of fuel usage overtime as countries promote ways to increase adoption of lower carbon fuels, with the transport sector being a major player in this regard. The assessment of the role/impact of natural gas consumption (through natural gas vehicle proliferation) on economic growth and other economic indicators is one avenue through which the energy-growth nexus can be addressed.

In assessing the linkage between gas consumption and economic growth, this study considers the four commonly used hypotheses put forth by Apergis and Payne [4]. These hypotheses are used to explain the unidirectional causality between energy consumption and economic growth, namely: (i) the growth hypothesis, suggesting that energy consumption has a significant impact on economic growth, which can also be in relation to other economic factors such as labour and capital; (ii) the conservation hypothesis, explaining that energy consumption is driven by economic growth; (iii) the feedback hypothesis, suggesting the presence of an interdependent relationship (bidirectional causality) between energy consumption and economic growth; and lastly, (iv) the neutrality hypothesis, indicating that energy consumption has no significant impact on economic growth. These views will be adapted in discussions of the results to conform this study to others in literature. Conversely, the existence of a bidirectional causality may also be of interest, as this is the more likely the reality in many countries.

While several studies have explored the relationship between energy consumption and economic growth, and alternative energy consumption and economic growth, some have gone further to focus on specific sources such as NGC and its impact on economic growth. Likewise, while studies in the past have examined different country groupings, such as the Organisation for Economic Co-operation and Development (OECD) [5], the EU[6], Organization of the Petroleum-Exporting Countries (OPEC) [7], Group of Seven (G7) [8, 9] countries, top 10 NGC countries [10] etc, none of them have focused on the dynamics at play involving the top NGV consumers, which will potentially influence the dynamics of gas consumption and economic growth for the rest of Europe as well. In exploring the relationship between gas consumption and economic growth, the present study focuses on the 10 largest markets of NGV users in Europe (see Tables A.1 and A.2 in appendix A for selected statistics indicators on selected countries), which include (from largest to smallest) Italy, Germany, Bulgaria, Sweden, the Czech Republic, France, Switzerland, the Netherlands, Austria and Hungary. Ireland is also included (for the sake of comparison with a country on the verge of NGV market development), as well as the UK, as the major gas exporting partner of Ireland. Ireland is en route to developing a NGV market and, given that Ireland as a country uses a large share of its NG for electricity generation, further inquest into the linkages between energy usage (NG) and economic growth will contribute to the growth of an NGC nexus. This current study adds to this body of evidence by taking a closer look at a smaller group of countries (top 10 consumers plus the UK and Ireland), while exploring their NGC as one of the potential sources of alternative energy as well as identifying their causes and impact to relative economic indicators, to provide findings that can prove useful for both its policy and awareness.

This study employs both the fully modified ordinary least square (FMOLS) and the dynamic ordinary least square (DOLS) method, due to its ability to provide consistent estimates when dealing with small data sets. We also make use of the Dumitrescu and Hurlin (D–H) [11] method, to further ascertain the direction of the relationship between economic growth and NGC. Evidence of the growth hypothesis is found for Bulgaria, Switzerland and Austria, while Italy and the UK exhibited the feedback hypothesis. The remaining countries supported the neutrality hypothesis.

The rest of the paper is organised as follows: Section 2 presents a brief review of the literature, section 3 describes the data and presents the methodology, and in section 4, the results are presented and discussed. In section 5, the conclusion and policy implications are given.

2 Literature on NGC and economic growth

Several studies in literature have examined the causal relationship between NGC and economic growth. Indeed, a couple of studies have provided a good survey of literature setting out methods for understanding this relationship [6, 7, 9, 12, 13]. Several of these studies have commonly cited literature showing data period covered, countries covered, methodology employed and causality relationship identified. Additionally, Table 1 is presented to show a summary for selected panel data studies on NGC and economic growth. Overall, what is observed from these literature surveys is structured literature on commonly applied multivariate model frameworks (methods), variables employed, findings and policy implications regarding NGC and growth nexus. For example, [7] provided a table of up to 31 case studies, with literature mostly relevant to OPEC countries. Similarly, [9] expounded on numerous studies, albeit more focused on European countries. A central concern in most of the cases cited in these studies, as well as the actual articles themselves, was the direction of the relationship (causality) between NGC and economic growth.

Table 1: Summary for selected panel data studies on natural gas consumption and economic growth

Auth-or(s)	Period	Country/ group	Variables	Methodology or methods	Relationship, Cointegration	Causality relationship
[5]	1991-2013	26 OECD countries	NGC, real GDP, GFC, TLF, TO (all per capita)	-LLC and IPS unit root tests Pedroni cointegration test. FMOLS and DOLS. VECM Granger causality test -country specific causal relationship test by Dumitrescu and Hurlin [11], & Sequential Panel Selection Method (SPSM) [14]	Variables are cointegrated with endogenous structural breaks. FMOLS & DOLS indicate NGC, GFC & TO positively affect GDP	NGC→GDP in short-run. NGC↔GDP in long-run
[6]	1997-2011	26 EU member states	GFC, GDP per capita, GFC, labour force	-Fisher-ADF & Fisher-PP unit root tests -Pedroni residual cointegration tests -Generalized Method of Moments - Engle and Granger error correction model	Positive relationship between GDP & NGC. Cointegration between all variables. Long-run relationship between all variables	NGC↔GDP in the short-run
[9]	1970-2008	G7	Real GDP, NGC, Capital	Bootstrap-corrected Granger causality	No cointegration test	NGC≠GDP
[8]	1965-2011	G7	Real GDP, NGC,	Granger causality test following [15], VAR model. Cross-sectional dependency & heterogeneity across countries.	No cointegration test	NGC≠GDP for panel NGC≠GDP for individual country results except UK
[10]	1994-2015	Top 10 NGC countries	GDP, NGC, TTGS (for TO indicator)	-Followed GDP growth model by [16] -Choi, IPS, and Maddala-Wu unit root tests -Granger causality test, cointegration test -FMOLS, DOLS	-Long run relationship between NGC & GDP. NGC has significant & +ve impact on GDP in long run	NGC↔GDP in panel (whole) short-run (temporary) and long-run (permanent)
[4]	1992-2005	67 countries	Real GDP, NGC, Labor, capital	-Pedroni cointegration -Granger causality	Cointegration presence Long-run equilibrium relationship between GDP, NGC, CF, LF	NGC↔GDP in short run

NB: NGC - natural gas consumption; GDP - gross domestic product, GFC - gross fixed capital formation;
TTGS - total trade of goods and services; TO – trade openness; TLF – total labour force; VECM – vector error-correction model
NGC→GDP indicates there is growth hypothesis, a presence of causality from natural gas consumption to economic growth
GDP→NGC indicates there is conservation hypothesis, a presence of causality from economic growth to natural gas consumption
NGC↔GDP indicates there is feedback hypothesis, a presence of bidirectional causal relationship between natural gas consumption and economic growth
NGC≠GDP indicates there is neutrality hypothesis, a case of no causal relationship between natural gas consumption and economic growth

Rather than repeat these studies in literature, we mention exemplary cases that cover countries closer to our selection group. Looking at studies that include some of our selected countries, [9] found, using the G7 data period from 1970 to 2008, Granger causality between NGC and growth for Italy and an adverse case for the UK, while France and Germany showed bidirectional Granger causality. In a panel study of EU member states, [6] made use of the fully modified OLS (FMOLS) estimation technique in assessing a panel of 26 European countries over the period running from 1997 to 2011. They found evidence in support of the feedback hypothesis in the short run.

Apergis and Payne [4] carried out a similar study but for a much broader selection of countries (67 countries). Many of these studies, given their cross-sectional nature, often report findings and bloc characteristics. While such information is useful at the initial stages of an inquest into a specific nexus area such as NGC and economic growth, the goal should be to find a way in which to factor individual country characteristics, hence reducing bias because of unobserved heterogeneity. Such bias limits understanding of per country relationships and explanations, as EU countries vary significantly regarding the size of their NGC, size of total primary energy supply, and diversification of use. As such, suggested policy implications from a broader group can be limited. We therefore limit our country selection to 12 markets in Europe, and tease out individual country characteristics, as exemplified by [5].

In the Destek [5] study, 26 OECD countries were considered, including some of the countries selected in our study but excluding Bulgaria, Hungary and the Czech Republic. Of special interest to our study is the Dumitrescu and Hurlin (D–H) [11] approach to teasing out individual country characteristics. In this study, a similar testing procedure is used, along with D–H causality [11] at individual country level. This allows for a comparison of the Destek [5] results with observed study findings[4]. Nonetheless, based on D–H results, [5] found the following evidence: the growth hypothesis for Austria and France; the conservation hypothesis for Ireland and the Netherlands; the feedback hypothesis for Italy, Sweden, Switzerland and the UK; and the neutrality hypothesis for Germany.

3 Methodology framework

Following the works of Ozturk and Al-Mulali [17] and Destek [5], this study employs a neoclassical model and a production function, according to which output growth is determined by the general consumption level of the economy. Causality is examined, as well as long-run relationships between NGC and economic growth. To this end, the impact of NGC, total trade as a share of GDP, gross fixed capital formation, and labour force, on real GDP as a panel series, is examined. The annual data employed in this study are sourced from the World Development

[4] Although the study mentions the use of the variable total labour force, this was omitted in the described function.

Indicators of the World Bank and BP Statistical Review of World Energy. The data covers the period from 1991 to 2016. This is to avoid the use of an unbalanced panel distribution, as some of the countries only have data starting at 1991. A balanced panel distribution was chosen for easier comparison of the results.

A consistent occurrence in the analysis of most of the studies reviewed in literature is the determination of the direction of causality. In doing so, three steps are often followed, namely: (i) the test for unit root and stationarity property, (ii) the cointegration test, and (iii) the causality test. The unit root test is done to determine the stationarity properties of variables. The stationarity of a series can strongly influence its behaviour and properties [18]. It is further important because it minimises the possibility of obtaining inconsistent estimates. The unit root tests used for this study are individual root tests of Fisher – Augmented Dickey Fuller, Phillips Perron, and Im, Pesaran and Shin (henceforth referred to as IPS) are applied.

Upon ascertaining whether or not the variable of interest contains unit roots or not, the cointegration test is carried out. This helps identify the presence of long-run co-movement among the variables. The causality test is often undertaken to determine direction of influence between variables, and whether this relationship dynamic is in the short-run or the long-run. As previously mentioned, to assess the linkage between gas consumption and economic growth, four hypotheses which describe this relationship and have also been put forth in literature, are considered, namely: the growth hypothesis; conservation hypothesis; feedback hypothesis; and neutrality hypothesis [5]. The main concern of this study is the existence of the growth hypothesis, which states that gas consumption unidirectionally causes economic growth.

This study employs the fully modified ordinary least square (FMOLS) and the dynamic ordinary least square (DOLS) method of Philips and Hansen [19], modified by Pedroni [20], for the panel long-run estimation procedures. This method is used because it helps account for potential endogeneity problems and provides consistent estimates when dealing with relatively small data observations. This comes in very handy, since the standard ordinary least square (OLS) provides inconsistent and inefficient results in such a case [21]. In addition, this method is considered appropriate in this study due to its applicability in the presence of nonstationary variables [21-23]. The panel unit root test is conducted to determine whether the chosen estimation technique would provide consistent estimates or not. In the presence of non-stationarity, the traditional methods of investigating causal relationships, such as the Granger causality approach, would give inconsistent estimates. Additionally, panel cointegration tests is also done to verify the presence of long-run co-movement among the variables. Finally, a panel causality test using the vector error correction model (VECM) as well as the Dumitrescu and Hurlin (D–H) [11] method was conducted to investigate the direction of the relationship between economic growth and NGC.

3.1 Panel stationarity tests

The unit root and cointegration tests are carried out to determine the order of integration of the series and the cointegrating equations among the series, respectively. There is a need to confirm that all the variables in the model are integrated of the same order. In doing so, five different panel unit root tests (known as the multiple series unit root tests) are employed: Fisher tests using the Augmented Dickey Fuller (ADF) and the Philip Perron (PP) tests (Maddala and Wu, 1999 and Choi, 2001) [24, 25]; Hadri [26]; Breitung [27]; Levin, Lin and Chu (henceforth referred to as LLC) [28]; and IPS [29]. This study will employ the latter tests (ADF, PP, IPS) because they are more powerful and less restrictive than the former, which do not permit autoregressive coefficient heterogeneity. According to Bangake and Eggoh [30], the proposed test of IPS assumes heterogeneity of units in the dynamic panel context, thereby dealing with potential serial correlation problems exhibited in Levin and Lin [31].

The panel unit root for the ADF regression equation is specified as:

$$\Delta y_{it} = \alpha y_{it-1} + \sum_{j=1}^{\delta_i} \psi_{ij} \Delta y_{it-1} + X'_{it}\gamma + \xi_{it} \qquad 3.1$$

with the null hypothesis:

$H_0\colon \alpha_i = 0$, for all i 3.2

where i is construed to be a non-zero fraction of a specific process, which is stationary.

3.2 Panel cointegration

For the purpose of this study, we consider the residual-based panel fully modified OLS (FMOLS) estimator by Pedroni [20] and Mark and Sul [32], which produces normally distributed, asymptotically unbiased coefficient estimates. The empirical model is specified in Equation 3.3.

$$y_{i,t} = \phi_0 + \boldsymbol{\chi}_{i,t}{}'\beta + \boldsymbol{D}_{1i,t}{}'\gamma_{i,t} + u_{1i,t} \qquad 3.3$$

where $\boldsymbol{D}_{i,t} = (\boldsymbol{D}_{1i,t}{}', \boldsymbol{D}_{2i,t}{}')'$ are the deterministic trend regressors, while the system of equations (Equation 3.4) governing the n stochastic regressors, $\boldsymbol{\chi}_{i,t,}$ is explained by Equation 3.4.

$$\boldsymbol{\chi}_{i,t} = \Gamma_{21i}^{\prime\boldsymbol{D}_{1i,t}} + \Gamma_{22i}^{\prime\boldsymbol{D}_{2i,t}} + \epsilon_{2i,t} \qquad 3.4$$

where $\Delta\epsilon_{2i,t} = u_{2i,t}$. Deterministic trend regressors, $\boldsymbol{D}_{2i,t}$, are included in regressor equations but not in the cointegrating equation, while $\boldsymbol{D}_{1i,t}$ regressors enter the cointegrating equation as well as the regressor equations. However, when the deterministic trend term only consists of cross-section dummy variables, the panel cointegrating equation follows Equation 3.5.

$$y_{i,t} = \phi_0 + \boldsymbol{\chi}_{i,t}'\beta + \gamma_i + u_{1i,t} \qquad 3.5$$

where $\Delta\boldsymbol{\chi}_{i,t} = u_{2i,t}$. The model proposes independence of y_t, u_t and χ_t and hypotheses that χ_t is not cointegrated.

3.3 Panel long-run estimation techniques

Given a cointegrated series, the study will investigate the long-run relationship between the identified parameters using the FMOLS and DOLS cointegrating regression estimation method. The FMOLS estimators below summarise their ability to deal with endogeneity and serial correlation problems, explained by Equation 3.6.

$$\hat{\beta}_{fmols} = \left[\sum_{t=1}^{T}(\boldsymbol{\chi}_{i,t} - \overline{\boldsymbol{\chi}}_{i,t})\,(\boldsymbol{\chi}_{i,t} - \overline{\boldsymbol{\chi}}_{i,t})'\right]^{-1} \left[\sum_{t=1}^{T}(\boldsymbol{\chi}_{i,t} - \overline{\boldsymbol{\chi}}_{i,t})\hat{y}_{i,t}^{+} - T\lambda_{21i}^{+}\right] \qquad 3.6$$

The FMOLS fitted values are $\hat{y}_{fmols} = \boldsymbol{\chi}_i\hat{\beta}_{fmols}$ and the FMOLS fitted residuals are $u_{fmols} = y_i - \boldsymbol{\chi}_i\hat{\beta}_{fmols}$.

Empirical model for this study is econometrically specified as:

$$LNGDP_{it} = \vartheta_0 + \vartheta_1 LNGCP_{it} + \vartheta_2 LNGCF_{it} + \vartheta_3 LNLBF_{it} + \vartheta_4 LNTRD_{it} + \epsilon_{it} \qquad 3.7$$

where $LNGDP$ means the natural log of real GDP per capita; $LNGCP$ means the natural log of per capita natural gas consumption; $LNGCF$ means the natural log of per capita gross fixed capital formation; $LNLBF$ means the natural log of total labour force; and $LNTRD$ means the natural log of per capita total trade.[5] ϵ_{it} is the error term; t is the time period while i is the cross section series.

The empirical panel FMOLS employed in this study is acquired by the panel estimation and the individual estimation of Equation 3.7. The DOLS estimation procedure used for this study is also acquired from the panel estimation and the individual estimation of Equation 3.7, but with the introduction of leads ($-K_i$) and lags (K_i) of the series as:

$$LNGDP_{i,t} = \begin{array}{l} \varphi_{0i} + \varphi_{1i} LNGCP_{i,t} + \varphi_{2i} LNGCF_{i,t} + \varphi_{3i} LNLBF_{i,t} + \varphi_{4i} LNTRD_{i,t} \\ + \sum_{k=-K_i}^{K_i} \theta_{ik} LNGCP_t + \sum_{k=-K_i}^{K_i} \beta_{i,k} LNGCF_t + \sum_{k=-K_i}^{K_i} \omega_{i,k} LNLBF_t \\ + \sum_{k=-K_i}^{K_i} \delta_{i,k} LNTRD_t + \epsilon_{i,t} \end{array} \qquad 3.8$$

This estimation method is considered suitable when there is a single cointegrating vector among variables that are I(1) process, but the explanatory variables are not cointegrated. This implies that the method is appropriate when a long-run relationship exists among the variables employed in the system and no separate cointegrating vector is found among the explanatory variables. We then employ the Granger causality test to determine the direction of causality within the series, using the panel VECM (see relevant equations and specifications in the Appendix).

[5] Gross domestic product (GDP) – per capita is measured as PPP constant 2011 international $. Natural gas energy consumption (GCP) is measured in billion cubic feet. Gross fixed capital formation is measured in constant 2010 US$. Labour force (LBF) is measured as people ages 15 and older who supply labour for the production of goods and services during a specified period. Total trade as share of GDP (TRD) is measured as addition of export and import as share of GDP.

3.4 Dumitrescu–Hurlin panel Granger causality test

This study takes a further step to tease out the nature of country-specific causality by employing the Dumitrescu–Hurlin Granger causality test[11], as specified by Equation 3.9. The Dumitrescu and Hurlin (D–H) test reports a Wbar statistic (average of test statistics), a Zbar statistic (standardised statistics) and the probability value, as well as the Zbar tilde statistic (standardised for the fixed T sample period). In this present study, *t* approaching T = 26 years and the corresponding cross-section size *i* to N=12 countries. Accordingly, the Wbar statistic relates to the cross-sectional average of the N standard individual Wald statistics of the Granger non-causality tests.

$$LNGDP_{i,t} = a_i + \sum_{k=1}^{K} b_i^{(k)} LNGDP_{i,t-k} + \sum_{k=1}^{K} c_i^{(k)} LNGCP_{i,t-k} + u_{i,t} \qquad 3.9$$

Lag orders are represented by K, which is automatically selected by the Akaike information criterion (AIC).

Hypotheses tests are as below:

(1) H_0: There is no causal relationship between gas consumption and real GDP growth. It stays the same, as gas consumption does not cause real GDP growth.
H_1: There is a causal relationship between gas consumption and real GDP growth.

(2) H_0: There is no causal relationship between real GDP growth and gas consumption. It stays the same, as real GDP does not cause gas consumption.
H_1: There is a causal relationship between real GDP growth and gas consumption.

4 Result and discussion

4.1 Stationarity and determination of order of integration

As discussed in the previous section, this study employs the Fisher-type ADF, PP tests, and IPS tests, which assume that δ_i varies across series, as they are more powerful and less restrictive than the assumed common unit root process, which does not permit autoregressive coefficient heterogeneity. The panel unit root test result is reported in Table 2.

Table 2: Panel unit root at level and first difference

Variable	ADF	PP	IPS	Variable	ADF	PP	IPS
LNGDP	18.2254 (0.7638)	13.0183 (0.9658)	0.7184 (0.7919)	D(LNGDP)	96.8184 (0.0000)	114.983 (0.0000)	–7.4400 (0.0000)
LNGCP	45.6049 (0.0049)	39.0534 (0.0270)	–3.2129 (0.0007)	D(LNGCP)	-	-	-
LNGCF	26.6419 (0.4301)	34.7640 (0.0720)	–0.1761 (0.4301)	D(LNGCF)	122.338 (0.0000)	163.071 (0.0000)	–8.8081 (0.0000)
LNLBF	20.6684 (0.6582)	28.0527 (0.2578)	1.1471 (0.8743)	D(LNLBF)	110.804 (0.0000)	127.981 (0.0000)	–8.2562 (0.0000)
LNTRD	19.0396 (0.7499)	44.7022 (0.0063)	0.4216 (0.6633)	D(LNTRD)	157.288 (0.0000)	-	–11.4974 (0.0000)

Note: Maximum lags were automatically selected by the Akaike information criterion (AIC) between 0 and 3 lengths.

The results suggest that we fail to reject the null hypothesis of unit root in the series at level for all the variables, except LNGCP, which is stationary at level. However, the null hypothesis of unit root can be rejected on LNGDP, LNGCF, LNLBF and LNTRD at first difference. This means that all the variables employed in this study are integrated of order one (I(1)), except LNGCP, which is integrated of zero (I(0)). The implication is that real GDP, NGC, gross fixed capital formation, labour force and trade openness are stationary series at the conventional level. Given a set of stationary series at first difference, this study further investigates whether any cointegrating relationship exists between the series that are I(1) process.

4.2 Panel cointegration results

A panel cointegration test is conducted for the I(1) process series, using the Pedroni cointegration test. This is to determine whether there is a long-run association between the variables in our series since they are not stationary at their levels. Table 3 presents the results for the panel cointegration test using an individual intercept, and no intercept or trend of the series. The results indicate a rejection of the null hypothesis of no cointegration, using panel PP and ADF statistics as well as Group PP and ADF statistics. The implication of this result is that there is strong evidence that real GDP, gross fixed capital formation, labour force and trade openness are cointegrated. In other words, although the individual series are not stationary at level, their residuals are stationary.

Table 3: Panel cointegration tests

Individual intercept			No intercept or trend		
Test	Statistic	*p*-values	Test	Statistic	*p*-values
Panel PP statistic	–2.9902	0.0014***	Panel PP statistic	–2.1142	0.0173**
Panel ADF statistic	–1.5556	0.0599*	Panel ADF statistic	–2.0037	0.0226**
Group PP statistic	–4.6269	0.0000***	Group PP statistic	–3.1691	0.0008***
Group ADF statistic	–3.7971	0.0001***	Group ADF statistic	–4.0973	0.0000***

Note: *, **, and *** mean a statistical significance level of 10, 5 and 1 per cent, respectively.

4.3 Panel cointegrating regression – FMOLS and DOLS results

With a long-run relationship between the series confirmed, the long-run parameters are estimated, using the panel FMOLS and DOLS estimation techniques. Table 4 presents the panel and country-specific cointegrating FMOLS results. The panel results show that NGC and the labour force significantly reduce GDP, while gross fixed capital formation and trade openness significantly increase it. The result shows that a 1% increase in NGC and labour force will reduce GDP by 0.097% and 2.112%, respectively, while a 1% increase in gross fixed capital formation and trade will increase GDP by 0.758% and 0.341%, respectively.

Table 4: Country-specific FMOLS results

Country	LNGCP	LNGCF	LNLBF	LNTRD	$\overline{R^2}$
Panel	–0.0970***	0.7582***	–2.1123***	0.3409***	0.6953
	(–4.1646)	(36.1392)	(–12.2872)	(8.1893)	
Italy	–0.3434***	0.7046***	–0.1861*	0.4477***	0.8202
	(–38.0297)	(116.8762)	(–1.9311)	(57.8846)	
Germany	–0.2061**	0.7586***	–1.2551***	0.3443***	0.9156
	(–2.1358)	(6.5620)	(–4.0925)	(5.1951)	
Bulgaria	–0.4202***	0.2037***	–0.5193***	0.9308***	0.9149
	(–23.6986)	(27.9308)	(–4.6748)	(72.9468)	
Sweden	0.0595**	0.7027***	–0.2509	–0.0154	0.9819
	(2.1928)	(15.3963)	(–0.8156)	(-0.2478)	
Czech Rep.	–0.2237***	0.6816***	–2.4117***	0.2339***	0.9744
	(–3.4804)	(18.1225)	(–3.6012)	(4.7577)	
France	–0.0558**	0.8383***	–1.9679***	0.2320***	0.8722
	(–2.2950)	(45.5069)	(–8.9955)	(9.0681)	
Switzerland	–0.1923***	0.8281***	–0.8603**	0.1753**	0.9069
	(–3.9836)	(10.2540)	(–2.2245)	(2.1027)	
Netherlands	–0.2654**	0.8144***	–0.4627**	0.2592**	0.8563
	(–2.2085)	(17.0870)	(–2.4850)	(2.2081)	
Austria	0.1298***	0.2939***	0.7367***	0.4155***	0.9822
	(5.0004)	(3.9326)	(6.7405)	(10.8162)	
Hungary	0.1978***	0.3378***	1.5337***	0.1529***	0.9799
	(3.4893)	(5.5529)	(8.5694)	(4.5217)	
UK	0.1400***	0.6012***	2.9957***	0.2999***	0.9645
	(4.0685)	(8.1558)	(6.1073)	(3.8311)	
Ireland	–0.8308***	0.3584***	2.3360***	0.6501***	0.9545
	(–7.8028)	(6.4307)	(5.5480)	(8.7854)	

Note: * indicates that the estimate is significant at 10%, while ** and *** show a significance level of 5% and 1%, respectively.

The country-specific FMOLS results show that NGC reduces real GDP in Italy, Germany, Bulgaria, the Czech Republic, France, Switzerland, the Netherlands and Ireland. On the other hand, NGC increases real GDP in Sweden, Austria, Hungary and the UK. The highest magnitude of the effect of NGC on real GDP is felt in Ireland, with its real GDP being reduced by 0.831% when there is 1% increase in NGC. In addition, the FMOLS results indicate that the labour force has a negative impact on real GDP in Italy, Germany, Bulgaria, the Czech Republic, France, Switzerland and the Netherlands.

The impact of gross capital formation is positive in all the economies considered, with the highest effect being seen in France. This means that a 1% increase in gross capital formation per capita will increase real GDP per capita in France by 0.838%. Per capita trade also affects real GDP per capita positively in all the economies, except in Sweden, where the estimate is not statistically significant. The findings show that the highest effect of per capita trade on per capita real GDP is found in Bulgaria. The results indicate that a 1% increase in per capita trade in Bulgaria will increase per capita real GDP by 0.931%.

Table 5: DOLS results

Country	LNGCP	LNGCF	LNLBF	LNTRD	$\overline{R^2}$
Panel	–0.0979***	0.7452***	–2.2474***	0.3423***	0.7770
	(–3.0832)	(28.2687)	(–9.8016)	(5.8233)	
Italy	–0.3122***	0.6933***	–0.2572***	0.5100***	0.9901
	(–46.7581)	(217.8609)	(–4.7416)	(73.1087)	
Germany	–0.1642***	0.8724***	–0.6740***	0.2644***	0.9634
	(–5.0377)	(28.8293)	(–9.2654)	(16.3491)	
Bulgaria	–0.1436***	0.3184***	–2.7495***	0.9969***	0.9978
	(–6.8901)	(40.5631)	(–19.6194)	(70.5786)	
Sweden	0.1085***	0.8474***	–0.1995***	–0.3407***	0.9988
	(11.9462)	(63.9799)	(–3.2398)	(–14.9872)	
Czech Rep.	–0.1612***	0.6545***	–3.4071***	0.2285***	0.9992
	(–6.9630)	(78.2291)	(–15.6434)	(16.3727)	
France	–0.2714***	0.8325***	–0.1710	0.2023***	0.9856
	(–10.7024)	(78.9414)	(–0.7075)	(12.3330)	
Switzerland	–0.1114***	1.1864***	1.6490***	–0.1324***	0.9951
	(–15.7833)	(72.9526)	(18.7719)	(–9.4090)	
Netherlands	–0.0546***	0.2723***	1.4292***	0.1349***	0.9994
	(–3.7488)	(21.9160)	(40.2350)	(13.3760)	
Austria	0.1245***	0.4629***	0.7395***	0.3935***	0.9990
	(6.1528)	(8.7876)	(11.6882)	(13.4381)	
Hungary	0.1845**	0.3338***	1.4564***	0.1538***	0.9816
	(2.2901)	(3.8034)	(6.0086)	(3.0362)	
UK	0.5112***	0.5860***	5.8099***	0.3050***	0.9932
	(23.9504)	(25.4941)	(32.5396)	(20.9580)	
Ireland	–0.7700***	0.3655***	2.1540***	0.6907***	0.9642
	(–6.3941)	(5.7200)	(4.4660)	(8.3943)	

Note: * indicates that the estimate is significant at 10%, while ** and *** show a significance level of 5% and 1%, respectively.

Table 5 presents results on both the panel and the country-specific cointegrating DOLS. As found in the FMOLS results, the panel DOLS results show that NGC and labour force significantly reduce gross domestic product, while gross fixed capital formation and trade openness significantly increase gross domestic product. The results show that a 1% increase in NGC will reduce GDP by 0.098%. The DOLS country-specific results are also consistent with the FMOLS country-specific results regarding the effect of NGC on per capita real GDP in all the NGV market economies considered, with the highest magnitude effect of 0.77% shown in Ireland. Given that the main focus of this study is the causal effect of NGC on economic growth, the negative relationship observed contradicts what the rest of literature has found. Furthermore, finding that NGC reduces real GDP in eight out of twelve (about 70%) of the economies considered, is concerning. Importantly, the findings confirm that the greatest negative effect of NGC on real GDP is found in Ireland, compared to other NGV market economies.

Table 6: Panel VECM results

Independent short-run results						Long-run results
Variable	ΔLNGDP	ΔLNGCP	ΔLNGCF	ΔLNLBF	ΔLNTRD	ECT(–1)
ΔLNGDP	-	0.0110	0.0259*	0.1211	–0.0144	–0.0189*
ΔLNGCP	0.0443	-	–0.0267	–0.4078	–0.0664	–0.1832***
ΔLNGCF	1.7582***	0.1417***	-	–0.0430	–0.1340**	0.1123***
ΔLNLBF	0.1038***	0.0054	0.0061	-	–0.0079	–0.0157***
ΔLNTRD	0.1390	0.0489	–0.0328	–1.2046***	-	–0.1020***

Note: * indicates that the estimate is significant at 10%, while ** and *** show a significance level of 5% and 1%, respectively.

Given a cointegrated panel series, the study employs a VECM Granger causality test to determine the direction of causality between NGC, gross fixed capital formation, labour force, trade openness and GDP in the NGV market economies. The panel short-run results in Table 6 suggest that gross fixed capital formation has a positive impact on the panel GDP in the short run, while NGC, labour force and trade openness have no significant impact on the panel GDP in the short run. The implication of this is that the growth hypothesis for NGC in the economies is not valid in the short run. However, the error correction term (ECT) is negative and statistically significant. This implies that NGC, gross fixed capital formation, labour force and trade openness have an impact on the panel GDP in the long run. Thus, the growth hypothesis for NGC is only valid in the long run. This result is consistent with the long-run cointegrating results from the FMOLS and DOLS in the previous section.

Considering the direction of causality between NGC and economic growth and the causal relationship with other variables included in this study, a unidirectional relationship can be noticed between gross capital formation and NGC, with NGC significantly affecting gross capital formation, while the same does not hold the other way around. However, with NGC and economic growth, no causality was found in either direction in the short run. Regarding other variables being considered, the result reveals that neither labour force nor trade openness has a causal impact on GDP in the short run. Looking at the causal impact of the other variables in the study, the results show no causality between gross fixed capital consumption, labour force and trade openness, and NGC in the short run.

Overall, regarding the other variables, evidence suggests that NGC is independent of gross fixed capital formation, the labour force and trade openness in the short run. Furthermore, no evidence of causality was found between NGC and the other two variables (labour force and trade), but some evidence was found of a causal impact of both GDP and NGC on gross fixed capital formation. In addition to all the above, it has also been found that only real GDP has a causal impact on the labour force in the short run.

4.4 D–H Granger causality tests

The advantage of the D–H test is the ease with which it deals with the causality hypotheses that are to be tested. In this test, it is clear, from the two scores reported, under which of the four briefly described hypotheses each of the 12 countries considered fall. This section limits causality tests to GDP and NGC. We have conducted two-way tests, with test 1 structuring NGC as the independent variable and real GDP per capita as the dependent variable. The test obtained a Wbar statistic of 2.6939, a Zbar statistic of 4.1492 with a p-value of 0.0000, and a Zbar tilde statistic (standardised for a fixed T-value) of 3.2861 with a p-value of 0.0010. Similarly, test 2 considered real GDP per capita as the independent variable and NGC as the dependent variable. The results obtained showed Wbar statistic of 1.8244, a Zbar statistic of 2.0193 with a p-value of 0.0435, and a Zbar tilde statistic (standardised for a fixed T-value) of 1.4934 with a p-value of 0.1353.

Table 7: Dumitrescu and Hurlin panel Granger causality test

Country	**X-gas consumption cause → Y-real GDP**	**(1)**	**X-real GDP cause →Y-gas consumption**	**(2)**
	Wald	***p*-value**	**Wald**	***p*-value**
Italy	0.3405	0.5595	8.5654	0.0034
Germany	0.9034	0.3419	0.0613	0.8044
Bulgaria	8.5831	0.0034	0.0795	0.7780
Sweden	1.2130	0.2707	0.0171	0.8960
Czech Republic	0.7305	0.3927	1.9891	0.1584
France	1.1114	0.2918	0.8388	0.3598
Switzerland	9.3434	0.0022	1.1899	0.2754
Netherlands	0.0007	0.9794	1.7557	0.1852
Austria	6.5822	0.0103	0.0532	0.8176
Hungary	0.3845	0.5352	1.2369	0.2661
UK	0.5419	0.4617	4.0727	0.0436
Ireland	2.5924	0.1074	2.0327	0.1539

NB: At lag 1, based on Akaike information criterion (AIC) selection.

Table 8: Dumitrescu–Hurlin results comparison to Destek [5] findings

Country	**Test 1**	**Test 1 – Destek**	**Test 2**	**Test 2 – Destek**
Italy	No	Yes**	**Yes*** **	**Yes*** **
Germany	**No**	**No**	**No**	**No**
Bulgaria	Yes***	n/a	No	n/a
Sweden	No	Yes***	No	Yes***
Czech Republic	No	n/a	No	n/a
France	No	Yes**	**No**	**No**
Switzerland	**Yes*** **	**Yes** **	No	Yes*
Netherlands	**No**	**No**	No	Yes***
Austria	**Yes*** **	**Yes*** **	**No**	**No**
Hungary	No	n/a	No	n/a
UK	No	Yes***	**Yes** **	**Yes*** **
Ireland	**No**	**No**	No	Yes*

NB: * indicates that the estimate is significant at 10%, while ** and *** show a significance level of 5% and 1%, respectively.

From the D–H causality test result (see Table 7), it is evident that most of the countries support the neutrality hypothesis, which indicates a minor or no significant impact of NGC on economic growth. For example, Bulgaria, Switzerland and Austria confirm the economic growth hypothesis. Italy and UK confirm the conservation hypothesis, while the rest support the neutrality hypothesis. In comparison to findings by [5], although using a different data period (1991–2013) to the period of this study, only Germany and Austria match the D–H outcomes[6] of the study. The comparison of the outcome of this study with that of [5] is represented in Table 8.

In the case of Bulgaria, 15% of energy used in the transport sector comes from NG, while 58% of NG-based energy is directed towards industrial use, suggesting NGC accounts for a significant proportion of energy usage in Bulgaria and making it plausible that NGC may indeed have an impact on economic growth. For Sweden, on the other hand, the evidence supports neutrality, which is not surprising when the transport sector share (5.2%), total primary energy supply (TPES) share (2%), and total imports (33.7 TJ) are considered. The D–H causality test indicates that Austria's NGC relates to GDP growth, while its GDP growth does not relate to the cause of NGC. The D–H inference should be taken with caution, given that only two relationships are observed between NGC and GDP.

5 Conclusion and policy implications

This study explored the relationship between natural gas consumption (NGC) and economic growth in 12 European countries, which included the top 10 NGV market and the UK and Ireland. The assessment has been based on the neoclassical growth model, which considers the role that natural resources play in economic growth. The data used in this assessment spanned the period from 1991 to 2016. In conducting this analysis, several long-run and panel cointegration estimation techniques were used to tease out both short-run and long-run relationship dynamics between NGC and economic growth.

[6] measured as PPP constant 2011 international $. Natural gas energy consumption (GCP) is measured in billion cubic feet. Gross fixed capital formation is measured in constant 2010 US$. Labour force (LBF) is measured as people

The results obtained are mixed. Evidence was found in support of a long-run co-movement between NGC and the four variables of interest (real GDP, gross fixed capital formation, labour force, and trade openness). Excluding specific country analysis, [6] observed a similar finding from a study of 28 EU member states involving relationship determination between GDP, NGC, labour and capital variables, and excluding gross fixed capital formation. This led to the conclusion that increasing economic output in the EU member states relates to increasing NGC, which on the other hand contributes to fall in economic development.

This study found evidence in support of the feedback hypothesis in the short-run. However, the long-run results present evidence of NGC, gross fixed capital formation, labour force, and trade openness having a long-run impact on economic growth. This confirmed the existence of the growth hypothesis in the long-run for the panel of 12 countries considered. The short-run relationship dynamics between NGC and economic growth did not produce strong results for the panel. However, evidence was found of short-run significant influence of NGC on gross fixed capital formation. Other than this, NGC seems to be a relatively independent phenomenon for the panel of 12 countries considered. It was found to be independent of economic growth, gross fixed capital formation, the labour force, and trade openness.

When the relationship dynamics between economic growth and the four other variables of interest are considered, we find that real GDP has a causal impact on both gross fixed capital formation and the labour force, while no evidence of the reverse was found. Further steps were taken to assess the individual country characteristics regarding NGC and economic growth. The overarching evidence supported the neutrality hypothesis (i.e. no influence in either direction), except in Austria, Bulgaria and Switzerland, which gave significant evidence of the growth hypothesis. That is, in Austria, Bulgaria and Switzerland, changes in the consumption of NG do influence economic performance. To avoid adverse effects of policy decisions on NG demand and consumption, planned and implemented NG policies should be taken with more consideration for these countries.

In comparison to other results obtained by [5], the results obtained for this study only confirm the outcome for two countries (Germany and Austria). Lastly, the FMOLS and DOLS analyses show evidence of a negative and significant relationship between NGC and economic growth in most of the countries considered, except in Sweden, Austria, Hungary and the UK, that is, countries that have experienced high levels of negative growth over the past decade. Therefore, while NGC does not influence economic performance directly for the considered data and period of this study, the potential impact it has on investment may pose an avenue of interest to policy makers. As such, the power of NGC can be harnessed for the European countries considered in this study. The countries covered are net importers of NG (see Table A.2 in appendix), with the exception of Netherlands having 1814 Terajoules (TJ) of local NG production and 1263 TJ of NG import in 2015. These makes them subject to international gas price volatility and supply shocks, while also availing to opportunities for cheaper fuel option to oil, and thereby a lower energy cost to consumers and investors, and lower national energy import value, and a contribution to emissions reduction targets. Substituting oil with natural gas is favoured across EU member policies, with confirmed carbon advantages over coal, diesel and petrol. This is already evident in residential energy source and is now favoured for vehicle fuelling. The European Directive 94/2014/EU [33] supports the deployment of alternative fuels infrastructure, which include development of regional NGV infrastructures. Such policy directions suggest the likelihood for increasing use of NG in the EU. As selected EU member countries differ in significance of NGC to economic growth, this revelation suggest member states will vary in sensitivity to shocks in gas price and policy, while influenced by common regional policy goal and approach.

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Appendix

Transportation use of NG globally stood at 2.7% in 1973 and at 6.9% in 2014 [34]. In 2016, European transport energy was comprised of 94% oil energy [35]. Table A.1 shows the figures for NGVs and NGV stations in selected countries, along with statistics on gas consumption and global market share in 2016. By and large, NGC has been directed more towards uses other than transportation in the EU. Table A.2 shows the ratio of transport energy to final NGC for the respective countries in 2015. To show the prevalence of NG in comparison to other energy sources, Table A.2 further shows the share of NGC directed towards electricity generation. In 2016, Ireland's share of NG usage stood at 55%, which is the largest percentage of the twelve selected countries. Other large share users of electricity included Italy (42%), Netherlands (46%), and the UK (43%).

Table A.1: 2016 statistics on the top ten NGV markets in Europe, the UK, and Ireland

Country	**NGV**	**NGV station**	**Total NG bcm cons**	**Cons share (%) to world**	**2016 growth rate (%) annum**	**Growth rate 2005–2015 (%)**
Italy	1 001 614	1 186	64.5	1.8	4.7	–2.5
Germany	93 964	885	80.5	2.3	9.2	–1.6
Bulgaria	69 820	125	3.0	0.1	3.9	–0.8
Sweden	54 379	173	0.9	<0.05	10.0	–0.9
Czech Republic	15 500	143	7.8	0.2	7.9	–1.7
France	14 548	60	42.6	1.2	9.0	–1.6
Switzerland	12 912	141	3.0	0.1	4.8	0.2
Netherlands	11 020	183	33.6	0.9	6.4	–2.3
Austria	7 084	172	8.7	0.2	4.4	–1.7
Hungary	6 314	10	8.9	0.3	7.0	–4.7
United Kingdom	310	38	76.7	2.2	12.2	–3.3
Ireland	8	1	4.8	0.1	14.0	0.8

NB: NGV and NGV station have been sourced from Natural & bio Gas Vehicle Association (NGVA) EU [36]. Total NGC and market share have been sourced from the BP Statistical Review of World Energy, which 'excludes natural gas converted to liquid fuels but includes derivatives of coal as well as natural gas consumed in Gas-to-Liquids transformation'. Cons denotes *consumption*.

Table A.2: Statistics on the top ten NGV markets in Europe, the UK, and Ireland

Country	2015 Transport energy share (%) to final NG cons	2016 NG fuel in TPES (%)	2016 NG (%) in electricity generation	2015 local NG production TJ thousand	2015 NG import in TJ thousand
Italy	3.2	39	42	258	2 334.2
Germany	0.8	23	13	294.7	3 997
Bulgaria	15	14*	<0.05*	3.9	117.2
Sweden	5.2	2	1	0	33.7
Czech Rep.	1.3	17	4	9.5	286.8
France	0.5	16	6	0.9	1 835.2
Switzerland	1.2	13	1	0	132.7
Netherlands	0.2	40	46	1814	1 263.1
Austria	5.7	22	13	48.3	438.7
Hungary	0.6	31	20	63.7	264.1
UK	<0.05	39	43	1658.9	1 750.3
Ireland	<0.05	30	55	4.9	168.4

NB: The 2015 transport energy share of NGC has been sourced from IEA statistics. TPES denotes *total primary energy supply*. * are estimated values from 2015 due to missing 2016 data. TJ denotes *terajoule unit* on a gross calorific value basis.

Granger causality specifications

$$\Delta LNGDP_{i,t} = \begin{matrix} \alpha_{1i} + \sum_{p=1}^{m} \alpha_{11ip}\Delta LNGDP_{i,t-p} + \sum_{p=1}^{m} \alpha_{12i,p}\Delta LNGCP_{i,t-p} + \sum_{p=1}^{m} \alpha_{13i,p}\Delta LNGCF_{i,t-p} \\ + \sum_{p=1}^{m} \alpha_{14i,p}\Delta LNLBF_{i,t-p} + \sum_{p=1}^{m} \alpha_{15i,p}\Delta LNTRD_{i,t-p} + \gamma_{1i}\epsilon_{i,t-1} + u_{1i,t} \end{matrix} \quad A.1$$

$$\Delta LNGCP_{i,t} = \begin{matrix} \alpha_{2i} + \sum_{p=1}^{m} \alpha_{21i,p}\Delta LNGDP_{i,t-p} + \sum_{p=1}^{m} \alpha_{22ip}\Delta LNGCP_{it-p} + \sum_{p=1}^{m} \alpha_{23ip}\Delta LNGCF_{it-p} \\ + \sum_{p=1}^{m} \alpha_{24ip}\Delta LNLBF_{i,t-p} + \sum_{p=1}^{m} \alpha_{25i,p}\Delta LNTRD_{i,t-p} + \gamma_{2i}\epsilon_{i,t-1} + u_{2i,t} \end{matrix} \quad A.2$$

$$\Delta LNGCF_{i,t} = \alpha_{3i} + \sum_{p=1}^{m} \alpha_{31ip} \Delta LNGDP_{i,t-p} + \sum_{p=1}^{m} \alpha_{32i,p} \Delta LNGCP_{i,t-p} + \sum_{p=1}^{m} \alpha_{33ip} \Delta LNGCF_{i,t-p} + \sum_{p=1}^{m} \alpha_{34ip} \Delta LNLBF_{i,t-p} + \sum_{p=1}^{m} \alpha_{35ip} \Delta LNTRD_{i,t-p} + \gamma_{3i} \epsilon_{i,t-1} + u_{3i,t} \quad A.3$$

$$\Delta LNLBF_{i,t} = \alpha_{4i} + \sum_{p=1}^{m} \Delta LNGDP_{i,t-q} + \sum_{p=1}^{m} \alpha_{42i,p} \Delta LNGCP_{i,t-p} + \sum_{p=1}^{m} \alpha_{43ip} \Delta LNGCF_{i,t-p} + \sum_{p=1}^{m} \alpha_{44i,p} \Delta LNLBF_{i,t-p} + \sum_{p=1}^{m} \alpha_{45i,p} \Delta LNTRD_{i,t-p} + \gamma_{4i} \epsilon_{i,t-1} + u_{4i,t} \quad A.4$$

$$\Delta LNTRD_{i,t} = \alpha_{5i} + \sum_{p=1}^{m} \alpha_{51i,p} \Delta LNGDP_{i,t-p} + \sum_{p=1}^{m} \alpha_{52ip} \Delta LNGCP_{i,t-p} + \sum_{p=1}^{m} \alpha_{53ip} \Delta LNGCF_{i,t-p} + \sum_{p=1}^{m} \alpha_{54i,p} \Delta LNLBF_{i,t-p} + \sum_{p=1}^{m} \alpha_{55ip} \Delta LNTRD_{i,t-p} + \gamma_{5i} \epsilon_{i,t-1} + u_{5i,t} \quad A.5$$

where i is the cross-sections (1, 2, 3,…12 countries), m is the number of lag, and t is the period, while $\epsilon_{i,t}$ is the error term from the long-run regression estimation.