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Interpreting the dynamic nexus between energy consumption and economic growth: Empirical evidence from Russia

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Abstract: Research on the nexus between energy consumption and economic growth is a fundamental topic for energy policy making and low-carbon economic developing all over the world. Russia is the third largest energy consumption country, while little research has touched upon its energy consumption issue till now, especially its energy consumption and economic growth nexus. Therefore, this paper empirically investigates the dynamic nexus of the two variables in Russia based on the state space model. And the results indicate that, first of all, on average, there does not exist any significant linear causality between Russia's energy consumption and economic growth during 1990-2008. Secondly, a time-varying long-term cointegration between them is identified, which means their equilibrium nexus indeed changes over the time. Thirdly, ever since the year 2000, Russia's effort to improve energy efficiency has attained much progress, but the recent performance of Russia's energy saving has been less than ever before. Finally, the comparison results indicate that the consistency of energy consumption and economic growth in Russia appears the worst among BRIC countries, which reflects the complexity of Russia's energy-growth nexus.

Key words: Russia; energy consumption; economic growth

1. Introduction

It has been universally acknowledged that Russian Federation proves a key energy producing country, especially with abundant oil and natural gas resources. In 2008,

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the Russian primary energy production ranked the third in the world. Specifically, the proved reserves of oil and natural gas accounted for 6.3% and 23.4% of the total respectively, and the production of oil and natural gas accounted for 12.4% and 19.6% of the total respectively (BP, 2009).

However, besides the role of a key energy producing country, Russia actually is also a giant energy consuming countries. In 2008, its primary energy consumption also ranked the third all over the world with a percentage of 6.1% larger than that of the Middle East region (5.4%) and African continent (3.2%), only less than that of the US (20.4%) and China (17.7%) (BP, 2009).

Additionally, it is well-known that energy acts as the basis for economic growth, and sustainable economic growth can not maintain without sufficient energy consumption, hence, intuitively, the nexus of energy consumption and economic growth should be positive all the time. Does this logic hold in Russia? Does the effort for energy saving in Russia affect its economic growth? Does the nexus of energy consumption and economic growth in Russia differ from that in other BRIC countries? Little attention has been paid to these topics, which are not consistent with the key position of Russia in the whole world.

Against this circumstance, this paper is aimed to study the relationship between energy consumption and economic growth in Russia, and compare the relationship with that in other BRIC countries, so as to ascertain the role of energy saving for economic growth in Russia.

The rest of the paper is organized as follows. Section 2 presents an overview of the existing literature regarding the relationship between energy consumption and economic growth. Section 3 explains the empirical approach and data definition. Section 4 gives the empirical analysis results and Section 5 concludes the research.

2. Literature review

Research on the nexus between energy consumption and economic growth has attracted vast attention up to now, and much of them were focused on the causal relationship between them. To sum up, four results or *hypotheses* currently exist regarding the causality of energy consumption and economic growth, and a detailed overview of empirical literature on this causality can be seen from Odhiambo (2010), Ozturk (2010) and Chandran *et al.* (2010).

The first result referred to a unidirectional causality running from economic growth to energy consumption (Wolde-Rufael, 2006; Yoo, 2006; Mozumder and Marathe, 2007), which held that economic growth caused energy consumption, and that as the economy grew, the energy demand from different sections of the economy increased. It was also called the "*conservation hypothesis*". Under this circumstance, a country is not entirely dependent on energy for its economic growth and energy conservation policies can be implemented with little or no adverse effects on economic growth.

The second result, however, argued that it was the consumption of energy that caused economic growth, which econometrically meant a unidirectional causality running from energy consumption to economic growth exists (Narayan and Singh, 2007; Odhiambo, 2009). This argument implies that economic growth is dependent on energy consumption hence is called the "*growth hypothesis*".

The third result considered that both energy consumption and economic growth caused each other, which meant there was a bi-directional causality between energy consumption and economic growth (Glasure and Lee, 1997; Soytas and Sari, 2003; Paul and Bhattacharya, 2004). Consequently, it was also called the "*feedback hypothesis*".

The last result contended that there was no causal relationship between energy consumption and economic growth in either direction, which was referred to as the "*neutrality hypothesis*". In other words, energy conservation policies have little or no effect on economic growth (Cheng, 1997; Asafu-Adjaye, 2000; Paul and Bhattacharya, 2004; Wolde-Rufael, 2006; Odhiambo, 2009), and the change of economy may not affect the consumption of energy sources.

Although a number of studies have been conducted regarding the causality between energy consumption and economic growth in American countries (such as USA, Mexico, Brazil), African countries (such as South Africa, Algeria, Congo, Kenya, Sudan), Asian countries (such as India, Singapore, South Korea, Malaysia, Philippine), European countries (such as the UK, Italy, Portugal) etc., little research has been concerned about the causal relationship between the two variables in Russia Federation.

Additionally, compared with Russia's energy production, little attention indeed has been paid to the features of Russia's energy consumption, especially its link to the economic growth. Opitz et al. (1997) discussed the energy consumption of buildings in Moscow, and argued that the relatively high space-heating energy use in the building mainly resulted from the poor control of heat delivery from the district heating system of Moscow. Fromme (1996) analyzed the potentials and obstacles of energy conservation in the Russian manufacturing industry, and argued that in the early 1990s, considerable energy conservation could be achieved, and a general lack of awareness stemming from traditional thinking and structures, compounded by a lack of financing possibilities, constituted some of the most important obstacles for energy conservation in Russia. Korppoo (2005) pointed out that the current level of energy efficiency had potential to retard the economic recovery of the country and cause problems on the energy sector, hence Russia needed to improve the efficiency of energy. Apergis and Payne (2010) empirically discussed the nexus among carbon emissions, energy consumption and economic growth with a panel vector error correction model for eleven countries of the Commonwealth of Independent States over the period 1992-2004, and found that the impact of energy consumption on economic growth appeared sensitive to the inclusion of Russia in the panel data set. Specifically, the inclusion of Russia revealed that energy consumption had a negative impact on economic growth in the short-run. In this case, energy conservation policies that reduced carbon emissions might not adversely impact economic growth in the short-run. Overall, scare literature concerned with energy consumption of Russia can be found up to now.

Another point is that existing literature analyzing the relationship between energy consumption and economic growth appears mainly focused on their static relationship by constant parameter models. In fact, this is not completely consistent with the reality and not up to describing their dynamic relationship. Therefore, this paper is aimed to overcome this drawback and investigate the dynamic relationship between the two variables in Russia with the time-varying parameter cointegration models.

Consequently, the contribution of this paper is twofold. For one thing, this paper is attempted to explore the energy consumption issue of Russia. For another, the dynamic (time-varying) nexus between energy consumption and economic growth may be examined, which may provide some insights for the energy consumption policy making in Russia.

3. Empirical approach and data definition

3.1. Empirical approach

First of all, we are going to use the Granger causality test approach (Granger, 1988) to check the relationship between Russia's energy consumption and economic growth.

And then we investigate the quantitative relationship between the two variables. Actually, when it comes to the quantitative relationship of energy consumption and economic growth, common study tends to develop a regression model as follows.

$$Ln\_energy_t = \lambda + \omega Ln\_GDP_t + u_t \, , \qquad (1)$$

where Ln_energy is the log value of energy consumption, Ln_GDP is the log value of GDP， and λ and ω are the coefficients to be estimated with residual item u.

The parameters estimated from Equation (1), however, are constant and static with average implications. Hence, it is hard for them to reflect the dynamic relationship between energy consumption and economic growth in Russia. Against this shortcomings, in order to explore the possible time-varying relationship between the two variables of Russia, a state space model based on Equation (1) is developed as follows according to Harry (1991), Hamilton (1994) and Huang and Hueng (2008).

Observation equation: $Ln\_energy_t = \alpha_t + \beta_t Ln\_GDP_t + \varepsilon_t$,

State equation: $\alpha_t = \alpha_{t-1} + \xi_t$, $\beta_t = \beta_{t-1} + \zeta_t$. (2)

Suppose $Z_t = [1 \quad Ln\_GDP]$, $a_t = [\alpha_t \quad \beta_t]'$, $T_t = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$, $\eta_t = \begin{bmatrix} \xi_t \\ \zeta_t \end{bmatrix}$,

$Q_t = \begin{bmatrix} \sigma_\xi^2 & 0 \\ 0 & \sigma_\zeta^2 \end{bmatrix}$, $H_t = \sigma_\varepsilon^2$, then the state space model can be rewritten as:

Observation equation: $Ln\_energy_t = Z_t a_t + \varepsilon_t$,

State equation: $a_t = T_t a_{t-1} + \eta_t$,

where $\eta_t \sim iid\ N(0, Q)$, $\varepsilon_t \sim iid\ N(0, H)$, $E[\varepsilon_t \eta_t^{'}] = 0$, $t = 1, 2, \cdots, T$. (3)

In order to test whether the parameter estimation of the state space model is reliable, this paper also considers the time-varying cointegration between Russia’s energy consumption and economic growth. The common cointegration theory provided by Engle and Granger (1987) discusses the long-term equilibrium relationship between two variables with a constant parameter model, like Equation (1). However, Equation (3) based on the state space model is a time-varying model, where if Ln_energy and Ln_GDP are two integrated series with the same order, and the residual series ε_t in the observation equation of Equation (3) proves stationary, then we may still say there exist a cointegration between Ln_energy and Ln_GDP. Different from the common cointegration by the constant parameter model, this cointegration suggests a time-varying long-term equilibrium between them (Wang et al., 2006).

3.2. Data description

When studying the nexus between Russia’s energy consumption and economic growth in this paper, the sampling period ranges from 1990 to 2008 with annual series. Russia’s annual energy consumption data comes from the BP statistical review of world energy 2009 (BP, 2009), quoted in million tonnes of oil equivalent. And Russia’s economic growth variable refers to its real GDP, quoted by US dollars, which is obtained by our own calculations based on the nominal GDP and GDP growth rate from the World Development Indicators database (see Equation (4)).

$$GDP_t^{real} = GDP_{t-1}^{nominal} * (1 + GDP_t^{rate}) \quad (4)$$

In the empirical research here, we first attain the natural logarithmic values of Russia's energy consumption and real GDP, which can be shown from Figure 1.

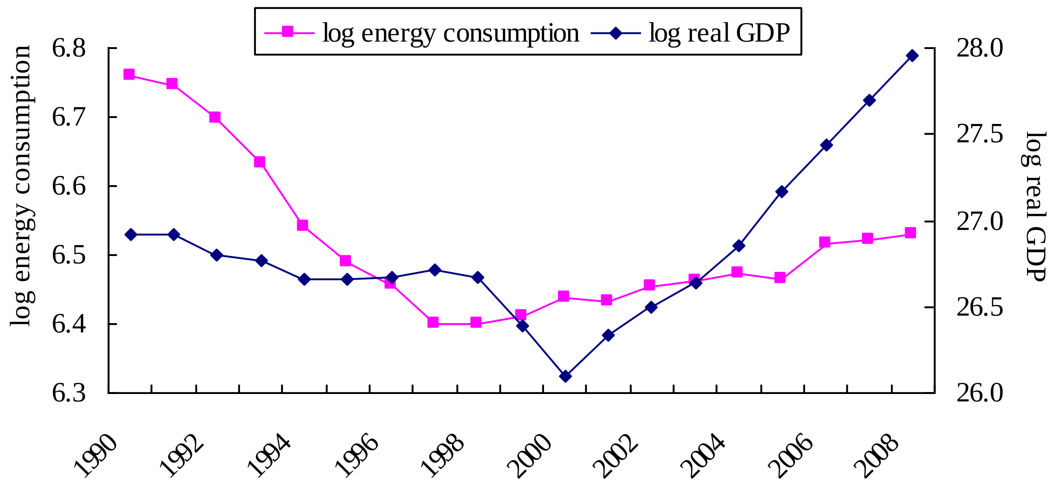


Fig. 1. Log values of Russia's energy consumption and real GDP during 1990-2008

We may find, from Figure 1, that Russia's energy consumption had an overall consistent trend with its economic growth. And three stages can be identified.

First of all, during 1990-1997, due to radical systemic transition and economic reorganization, the Russian economy experienced a deep recession (Korppoo, 2005), which decreased GDP by 17%. Total final energy consumption collapsed by 30% during the same period of time, which showed that Russia's economy became less energy intensive during this period. Specifically, energy intensity decreased 14% (see Figure 2).

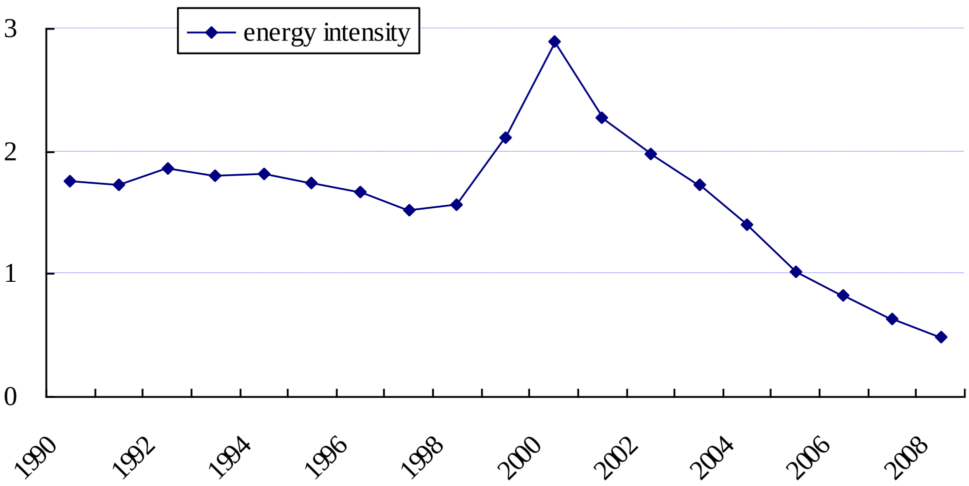


Fig. 2. Russia's energy intensity during 1990-2008

Note: energy intensity here is the energy consumption per unit of real GDP, where the energy consumption is quoted in million tonnes oil equivalent and the real GDP is quoted in billion US dollars.

On the second stage from 1998 to 2000, Russia's energy consumption did not go with economic growth hand in hand. Actually, energy consumption stopped the continuous decrease and began to climb gradually due to its traditional industrial structure with heavy energy consumption, meanwhile, incurred by the Asian financial crisis, Russia's economy continued to decline even in a sharper manner. Consequently, Russia's energy intensity witnessed an evident increase, which also can be found in Figure 2.

The last stage refers to the period ever since the beginning of the 21st century. On this stage, due to the economic reform and the staggering rise of oil and gas export revenues, Russia's economy began to grow fast, and energy consumption also received a steady increase. From 2001 to 2008, on average, annual 1.4% increase of energy consumption sustained 26.1% increase of economic growth, which suggested a sharp decline of energy intensity (see Figure 2).

Overall, due to the transition of Russia's economic system and the evolution of its energy market, the nexus between Russia's energy consumption and economic growth became fairly complicated, and its structure changed over the time. Therefore, a time-varying parameter model is imperative to examine their complex interaction.

4. Empirical results and discussions

4.1. The causality between Russia's energy consumption and economic growth

Based on the previous literature concerned, we conducted the Granger causality test for Russia's energy consumption and economic growth (see Table 1). And the results showed that there was no causal relationship between them in either direction during 1990-2008. According to the "*neutrality hypothesis*", it suggested, seemingly, energy conservation policies had little or no effect on economic growth in Russia.

Table 1

The causality test for Russia's energy consumption and economic growth during 1990-2008

Null Hypothesis	Obs.	F-Statistic	Prob.
Ln_GDP does not Granger cause *Ln_energy*		0.6158	0.5564
Ln_energy does not Granger cause *Ln_GDP*	17	1.1144	0.3598
Ln_GDP does not Granger cause *Ln_energy*		1.1675	0.3748
Ln_energy does not Granger cause *Ln_GDP*	16	0.6417	0.6072
Ln_GDP does not Granger cause *Ln_energy*		0.5102	0.7318
Ln_energy does not Granger cause *Ln_GDP*	15	0.7631	0.5857
Ln_GDP does not Granger cause *Ln_energy*		3.1968	0.1838
Ln_energy does not Granger cause *Ln_GDP*	14	1.3310	0.4332

Note: the estimation above is conducted on the corresponding logarithmic values, where *Ln_GDP* denotes the Russia's log real GDP and *Ln_energy* denotes its log energy consumption. Different observations correspond to different lags during estimation so as to get the robust causality test results.

Actually, we do not completely agree with this viewpoint for several reasons. For one thing, the Granger causality test implies an average meaning, but not a dynamic description of the nexus of Russia's energy consumption and economic growth. For another, the structure of their nexus has been changed a lot during 1990-2008, so the common linear Granger causality test above can not fully portrait the complexity.

4.2. The dynamic nexus of Russia's energy consumption and economic growth

We are attempted to adopt the state space model to measure the dynamic nexus of Russia's energy consumption and economic growth.

First of all, as usual, according to Equation (1) above, we conduct the OLS regression for the two variables during 1990-2008, and attain the parameter estimation results in Table 2, which represent their quantitative nexus in an average meaning. We may find that neither the probability for the regression equation nor the variable is significant, and the adjusted R-squared proves very small, which indicate that the information of Russia's energy consumption change can not be explained much by the change of its economic growth. This result is considerably counter-intuitive. Hence, the constant parameter model, with limited explaining power, is not up to describe the complex nexus of the two variables, and the regression result can not provide any important hints for related policy making.

Table 2

OLS estimation results of the constant parameter model for Russia's energy-growth nexus

	Coefficient	Std. Error	t-Statistic	Prob.
Constant	4.7401	1.5294	3.0994	0.0065
Ln_GDP	0.0662	0.0570	1.1620	0.2613
R-squared	0.0736	F-statistic		1.3502
Adjusted R-squared	0.0191	Prob. (F-statistic)		0.2613

Note: the dependent and independent variables are Ln_energy and Ln_GDP respectively, and the sampling period is from 1990 to 2008.

Therefore, based on the Kalman filtering algorithm, the time-varying state variable of

Equation (3) is obtained (see Figure 3), which suggests the instability of the nexus of Russia's energy consumption and economic growth.

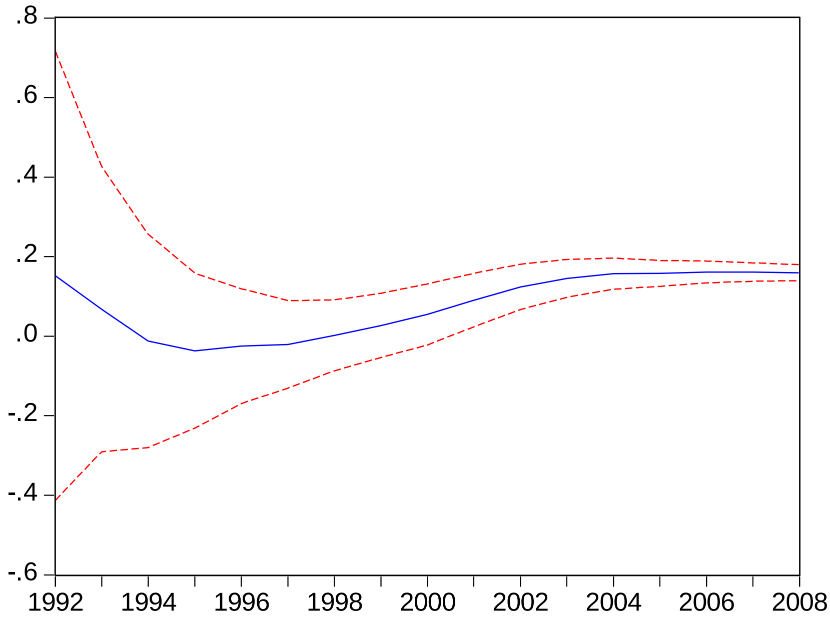


Fig. 3. The estimated state variable during 1992-2008

Note: the lower and upper dotted line means the 2 times minus and plus root mean square error (RMSE) respectively.

From the volatility of the state variable in Figure 3, we may find that the nexus of Russia's energy consumption and economic growth indeed changed over the time, which in turn demonstrates that it will be biased to make policies according to the results in Table 2. Specifically, their nexus witnessed a decline first and then a steady rise, and during some periods, the nexus appeared negative. Given our calculation is based on the logarithmic values, hence the state variable also indicates the elasticity of Russia's energy consumption to the GDP growth. Several implications can be obtained from the time-varying state variable.

First of all, from 1992-1994, the state variable saw a sharp decline. During this period, both Russia's energy consumption and GDP showed fast slow-down (see Figure 4), and energy consumption decreased faster than that of GDP. Consequently, the energy consumption slow-down per unit of GDP slow-down decreased significantly.

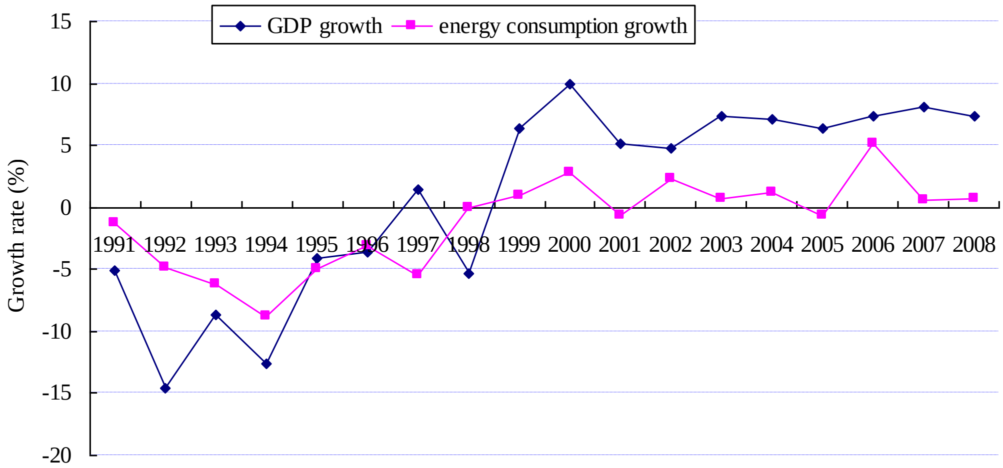


Fig. 4. GDP and energy consumption growth rates in Russia during 1991-2008

Second, from 1995-2000, the state variable even was found negative. This displays when GDP grew, energy consumption decreased, and when GDP declined, energy consumption ascended, which exhibits the reality of the changes of the two variables (see Figure 1).

Third, on the last stage since 2000, the nexus turned out positive and displayed a steady rise. This indicates, for one thing, when Russia's GDP initiated the recovery growth, its energy consumption also saw a stable increase (see Figure 1 and Figure 4); for another, however, the state variable was less than one all the time, which implied that Russia is promoting the energy efficiency[1], hence its energy intensity has been declining (also see Figure 2), but this task became more difficult these years and the performance appeared less evident than ever before.

To our knowledge, this fact is in line with the economic growth features in Russia. In recent years, for the sake of socio-economic sustainable development and the commitment in Kyoto Protocol, the Russian authority started to beware of the importance of energy efficiency and carbon emissions reduction. For this purpose, the Russian Energy Strategy recognized the need to save energy as one of the main points

[1] For example, in 2001, when Russia's GDP grew 1%, its energy consumption might increase 0.2%, which was suggestive of the effort to improve energy efficiency; and in 2008, when GDP grew 1%, its energy consumption increased 0.18%, which also indicated Russia's effort for energy efficiency, but comparatively, the performance was less evident than ever before.

of the country's energy policy (The Ministry of Energy of Russia, 2003), and the country have done a lot for the improvement of energy saving till now. However, after 2003, Russia's social political order became more stable, and its macroeconomic situation turned for the better, consequently, Russia's economy proved more investment-oriented with investment growth rate higher than economic growth rate. This inevitably caused an evident increase of energy consumption.

Another reason for the current situation is highly related with the energy consumption structure in Russia. For a long time, natural gas and oil have played the key roles in Russia's energy consumption. From Figure 5, we may find that the dominant energy sources are natural gas and oil, which accounted for 55% and 19% of the total in 2008 respectively, while the share of coal consumption appeared relatively lower. Therefore, it should be noted that the natural gas and oil consumption volume in Russia was huge based on its tremendous total energy consumption, and its economic growth was highly dependent on this two sources, but their domestic prices were much lower than those in the international markets. Consequently, it will be fairly hard for Russia to diminish energy consumption if its economic growth steadily develops without obvious industrial structure adjustment.

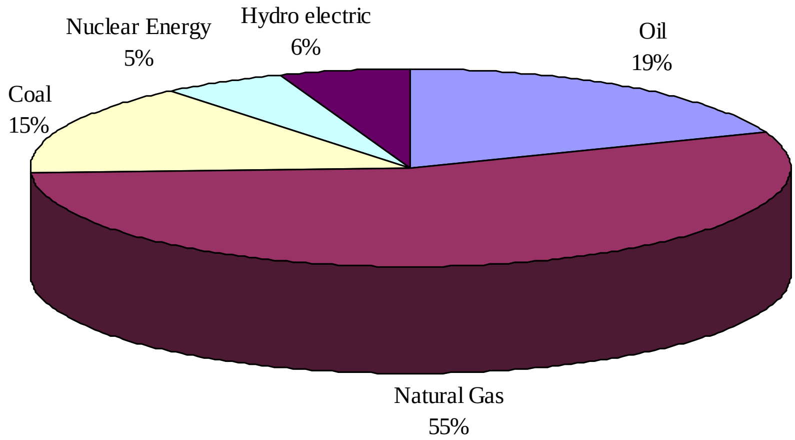


Fig. 5. The energy consumption structure of Russia in 2008

Source: BP (2009)

Moreover, the nexus on the last stage also indicates some in-depth features of

Russia's economic growth. For instance, in the past five years, Russia's economy witnessed a sharp growth mainly due to the oil and natural gas export revenue for their ever-increasing prices. A report from the World Bank showed that when oil price increased 1 US dollar per barrel, the share of Russia's fiscal revenue on its GDP might increase 0.35% (Ruehl, 2004). This indeed suggests the situation has no solid and long-term foundation. Just due to this kind of economic structure, the sharp decrease of international oil price from the last half of 2008 to 2009 caused 7.9% GDP decline in Russia. Actually, in order to obtain a sustainable development of Russia's social economy, the Russian government may have a long way to go to optimize its industrial structure and develop the advanced and low-carbon technology.

4.3. Validation of the time-varying parameter model

In order to validate the reliability of the time-varying parameter model, according to the cointegration theory, we conduct the ADF test for the stationary properties of regression residuals.

First of all, we test the stationary properties of Ln_energy and Ln_GDP, and results are shown in Table 3. we find that both of them are 2-order integrated series, which meets the precondition of cointegration regression.

Table 3

ADF test results for Russia's log energy consumption and real GDP series

	Ln_energy	Ln_GDP
Level	-0.5149 (0.4783)	-0.5587 (0.8558)
First difference	-3.4694 (0.0754)	-2.7734 (0.2240)
Second difference	-6.1657 (0.0000)	-3.9592 (0.0006)

Note: the ADF test is conducted for Ln_energy and Ln_GDP with regard to their stationary properties. The results are the values of corresponding t statistics, and p values are reported in parentheses.

According to the two-step approach provided by Engle and Granger (1987), we obtained the ADF test results for the residuals of Equation (1) and (3) respectively (see Table 4). The p values show that the residual series of constant parameter model does not appear stationary at 5% level, therefore, Equation (1) can not prove the long-term equilibrium relationship between Ln_energy and Ln_GDP; in other words, Equation (1) is more of a spurious regression.

However, we find that the residual series of the time-varying parameter model (i.e. Equation (3)) is stationary at 1% level, therefore, we may say the estimation of Equation (3) proves reliable, and the insights we have gotten from the dynamic state variable is of great significance. Overall, we can find the time-varying parameter model outperforms the constant parameter model in terms of the nexus of Russia's energy consumption and economic growth.

Table 4

ADF test results for the stationary properties of residuals

	Residuals of the constant parameter model	Residuals of the state space model
t statistics	-1.4043	-3.9472
p values	0.8236	0.0005

4.4. The nexus comparison of energy consumption and economic growth among BRIC countries

Ever since the beginning of the 21st century, four giant developing countries, Brazil, Russia, India and China, have witnessed continuous economic growth and become the powerful engine for the world economic growth, hence were often called the BRIC countries.

In order to compare the nexus of energy consumption and economic growth in Russia and that in other BRIC countries, we conducted the linear Granger causality test first, and results are shown in Table 5.

Table 5

The comparison of energy-growth causality test results among BRIC countries

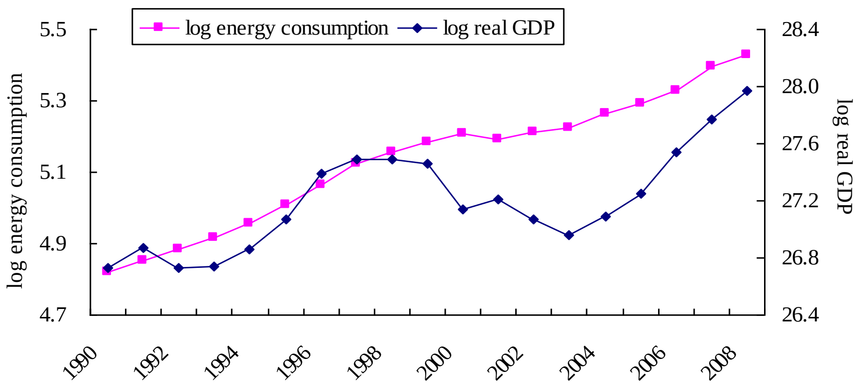
Null Hypothesis	F-Statistic	Prob.
Brazil's GDP does not Granger cause Brazil's energy consumption	11.6593	0.0015
Brazil's energy consumption does not Granger cause Brazil's GDP	7.2767	0.0085
Russia's GDP does not Granger cause Russia's energy consumption	1.1144	0.3598
Russia's energy consumption does not Granger cause Russia's GDP	0.6158	0.5564
India's GDP does not Granger cause India's energy consumption	3.3656	0.0691
India's energy consumption does not Granger cause India's GDP	2.9302	0.0920
China's GDP does not Granger cause China's energy consumption	2.7178	0.1063
China's energy consumption does not Granger cause China's GDP	3.3760	0.0687

Note: the causality tests above are conducted on corresponding logarithmic values, and each has the lag order 2.

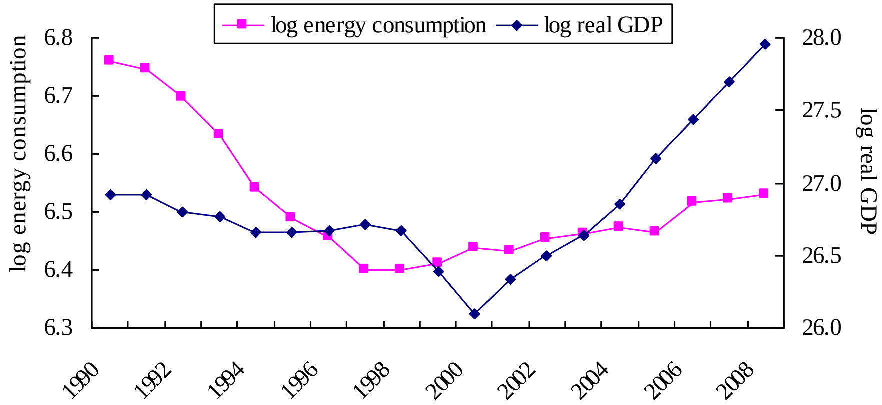
It should be noted that, firstly, only Brazil's energy consumption and economic growth have significant bi-directional causality at 5% or even 1% level, and the linear causality in other BRIC countries does not prove statistically significant.

Secondly, the estimation probabilities indicate that, among the four BRIC countries, the linear causality of Russia's energy consumption and economic growth seems the most insignificant; actually, at 11% level, significant bi-directional causality of energy consumption and economic growth may be identified in all other BRIC countries, but Russia fails. This result can, to some extent, reflect the most complicated situation between Russia's energy consumption and economic growth.

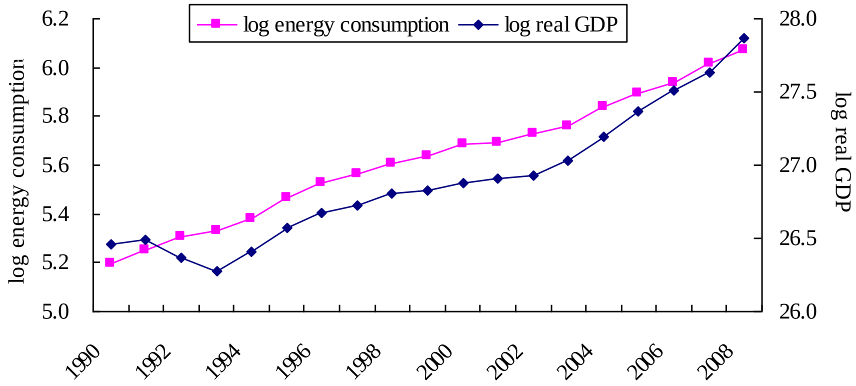
In fact, this argument can also be proved from Figure 5. Specifically, in India and China, the tendency of energy consumption and economic growth appears much in common. Consequently, from the regression results in Table 6, we may find that the independent variables are highly significant at 1% and the corresponding residuals are stationary, which reveals the cointegration of the two variables and the liability of the OLS regression for India and China.



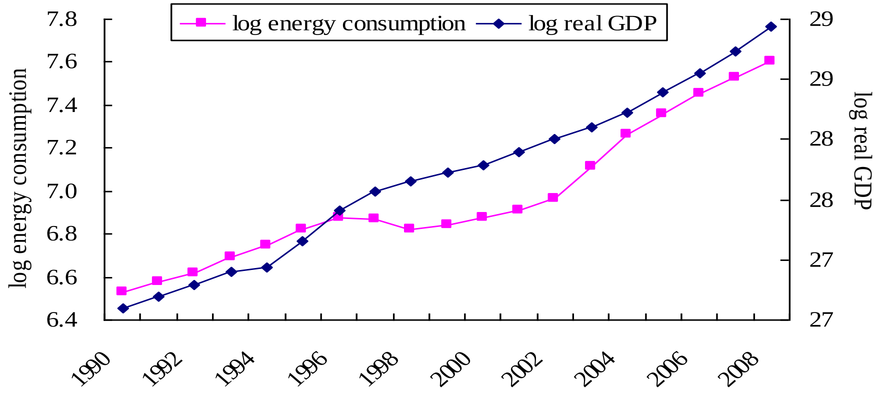
(a) Brazil



(b) Russia



(c) India



(d) China

Fig. 6. The tendency comparison of energy consumption and economic growth among BRIC countries during 1990-2008

Additionally, in Brazil, the OLS regression between its energy consumption and economic growth proves fairly significant, while the residual series is a little bit non-stationary even at 10%, which to some extent displays the inconsistency of its energy consumption and economic growth during 1997-2003.

Overall, energy consumption and economic growth in other BRIC countries may be much more consistent than those in Russia. As a result, the mot insignificant independent variable in OLS regression touches upon Russia, and the most insignificant residual also refers to Russia, which suggest that the consistency of energy consumption and economic growth in Russia appears the worst among BRIC countries.

Table 6
The comparison of OLS regression results between energy consumption and economic growth among BRIC countries

Dependent	Independent	Coef.	t-Statistic	Prob.	ADF test
Ln_energy_Brazil	*Constant*	-5.9964	-2.9417	0.0091	-3.3161
	Ln_GDP_Brazil	0.4091	5.4597	0.0000	(0.1014)
Ln_energy_Russia	*Constant*	4.7401	3.0994	0.0065	-1.4042
	Ln_GDP_Russia	0.0662	1.1620	0.2613	(0.8236)
Ln_energy_India	*Constant*	-9.2780	-8.6812	0.0000	-2.7388
	Ln_GDP_India	0.5542	13.9464	0.0000	(0.0091)
Ln_energy_China	*Constant*	-5.1156	-5.4711	0.0000	-2.6567
	Ln_GDP_China	0.4366	12.9313	0.0000	(0.0112)

Note: the term *Ln_energy_Brazil* denotes the log value of Brazil's energy consumption while *Ln_GDP_Brazil* denotes its log real GDP, and others items have the similar meanings. The ADF tests are conducted for the stationary properties of corresponding residuals, and *p* values are reported in parentheses.

Another difference of the nexus in Russia from that in other BRIC countries relates to the independent coefficient of OLS regression. We may find from Table 6 that the independent coefficients in other BRIC countries are much greater than that in Russia, which also testifies the worst consistency of energy consumption and economic growth in Russia.

Therefore, to sum up, compared with the nexus of energy consumption and economic growth in other BRIC countries, the nexus in Russia proves the most complex, besides its counter-intuitive attribute.

5. Conclusions and outlook

From the discussions above, it has been shown that the state space model appears more suitable for measuring the dynamic nexus of Russia's energy consumption and economic growth, while the common constant parameter model may cause spurious regression and is insufficient to describe the complex nexus between the two variables. To sum up, we have gotten some findings and policy implications.

First of all, the nexus of Russia's energy consumption and economic growth proved time-varying, even in some period, it went on negatively, which is counter-intuitive. Hence it is unsuitable to merely portrait the nexus in an average manner.

Additionally, ever since the year 2000, Russia's economy has witnessed a recovery growth, and the authority has started to take some measures to curb energy intensity and carbon emissions reduction. As a result, the energy efficiency in the country has achieved much promotion, while the marginal performance became more and more arduous. Behind the fact, among others, industrial structure optimization and low-carbon technology development may be two urgent outlets.

Finally, compared with other BRIC countries, we find that the consistency of energy consumption and economic growth in Russia appears the worst. This also reflects the complexity of energy saving policy making in Russia.

As for the future work, to our knowledge, Russia has signed the Kyoto Protocol in 2004, and as a large country for energy consumption, its global responsibility and position for energy saving and carbon emissions reduction have become heated topics all over the world. Hence research on the energy-saving modes and potential as well as the low-carbon development path should be of important directions in the future.

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