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How did the US economy react to shale gas production revolution? An advanced time series approach

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A B S T R A C T

This paper aims at examining the impacts of shale gas revolution on industrial production in the US. To this end, this paper, first, throughout literature review, exposes the features of shale gas revolution in the US in terms of energy technology and energy markets. However, the potential influences of shale gas extraction on the US economy are not explicit in the existing literature. Thus, considering mainly the output of shale gas revolution on the US economy in this research, later, the paper conducts econometric models to reveal if there exists significant effect(s) of shale gas revolution on the US economy. Therefore, the paper employs unit root tests and cointegration tests by following relevant US monthly data from January 2008 to December 2013.

Then, this paper observes long run impact of shale gas production on industrial production in the US through dynamic ordinary least squares estimation with dummy structural breaks and conducts Granger causality test based on vector error correction model. The dynamic ordinary least squares estimator explores that shale gas production has a positive effect on industrial production. Besides, the Granger causality test presents that shale gas production Granger causes industrial production in the long run. Based on the findings of the long run estimations, the paper yields that industrial production is positively related to shale gas production. Eventually, upon its findings, this paper asserts that (i) the shale gas revolution in the US has considerable positive effects on the US economy within the scope of the validity of the growth hypothesis, (ii) new technologies might be developed to mitigate the possible negative environmental effects of shale gas production, (iii) the countries having shale gas reserves, as in US, may follow energy policies to utilize their shale reserves more in the future to meet their energy demand and to increase their economic welfare.

1. Introduction

This work underlines explicitly two facts; the one is '*The shale gas revolution*' which depicts an outstanding development in production technology, and hence, considerable increase in production volume of shale gas in the US. The other one is '*The US economy's possible potential reaction to the revolution*'. The latter issue, to the best of our knowledge, has been uncovered quantitatively so far.

In order for us to be able to measure efficiently the quantitative causality from shale gas revolution to the US economy, we follow the methodologies to conduct time series analyses of high frequency US data.

Therefore, this work employs monthly industrial production index of the US as a proxy for monthly real economic activities of the US economy. To this end, we promote our research in this work by applying quantitative analyses through time series cointegration and causality models in which one might observe the short and long term quantitative responses of US monthly industrial production to the monthly shale gas production in the US for the period 2008:1–2013:12.

This section aims at (i) explaining what the 'shale gas revolution' is, and, (ii) underlining the motivation of this paper following the notion of shale gas revolution to reveal possible response of the US

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GDP to the intensive shale gas production.

Why is shale gas production in the US considered 'a shale gas revolution'? Before the 21st Century, obtaining natural gas from shales was thought impossible since, in the 20th Century, producers used to extract the sources of water, oil and natural gas through vertical wells [1]. The US succeeded, however, to extract prominent amount shale gas by the application of horizontal drilling and hydraulic fracturing in the US [2]. These new technological applications (i) enabled the US to supply excessively the liquefied natural gas and hence, in turn, (ii) caused gas prices to diminish across the countries in general [3]. Although there also exist other countries having massive sources of shale gas, none of them, unlike the US, could catch the shale gas production boom [4]. The US natural gas production exceeded the Russian natural gas production since 1982, and, natural gas spot price in the US declined from $8.69 per million BTU in 2005 to $2.75 per million BTU in 2012 [5]. The economic impact of shale gas extraction on the US economy, is, on the other hand, ambiguous [6,7] because no study concerning the effect of shale gas on GDP and/or employment is published in the literature [7], and, hence, since there appears scientific uncertainty of shale gas' significance in the literature [6].

The US, having massive natural gas production, and, hence, facing relatively lower energy prices, aims at, also, mitigating Greenhouse Gas (GHG) emissions through the usage of shale gas. Although there available some studies observing some possible negative effects of shale gas on environment, the majority of the works published in relevant literature [8–10] emphasize the positive influence of shale gas on environment by reducing the GHG emissions. Wang et al. [9] explore that the shale gas produces less GHG emissions than the coal produces when the greater power generation efficiency is provided in the long term. On the other hand, the drilling shale gas might affect environment negatively since it needs considerable amount of water resources. The usage of large volume of underground water might bring about excessive cost of shale gas production. Rahm and Riha [11], Rahm et al. [12], and Vengosh et al. [13] consider these potential possible environmental risks of extracting shale gas in terms of water sources. As Vengosh et al. [13] specifically underline the potential risks of shale gas drilling and hydraulic fracturing on the water source quality, Rahm and Riha [11] and Rahm et al. [12] suggest that authorities follow the features of regional water resources in designating competent management strategies for shale gas development across the countries in which rich shale gas reserves are available.

The environmental impact of shale gas is out of scope of this paper. This serious subject needs be launched, of course, in some potential future studies. This paper explicitly focuses on the economic effects of shale gas revolution in the US since there is no work, to the best of our knowledge, conducting a relevant data to measure the influence of shale gas drilling on the US economy. Some reports and/or papers also verify the gap in the literature investigating economic impulses of shale gas production within microeconomic and/or macroeconomic perspectives as explained in Melo-Martín et al. [6] and Kinnaman [7].

Shale gas is the natural gas that is squeezed in rocks below ground. In contrast to methods extracting natural gas and oil, the shale gas is extracted through hydraulic fracturing method together with pressurized water. Shale gas, which is called unconventional natural gas, is evaluated as the basic factor of the structural transformation of the US energy sector [14]. Many studies in the literature use statements "Energy Revolution", "Golden Age of Gas", and "The Biggest Energy Story of the US" for shale gas of which production has increased so much in a short time [2,15–22]. In fact, the developments in shale gas appear in 1970s. In these years, the oil crisis induced the US to focus on energy issues more, and thus the US government sought alternative energy sources and made R&D expenditures on energy sources including shale gas. The Gas Research Institute was established in 1977, then the National Energy Technology Laboratory was established in 1990, and large-scale companies began to enter the energy sector as a result of advancements in R&D of alternative energy sources. A structural transformation process began due to the hydraulic fracturing method developed by these companies. Even though important improvements occurred in shale gas production during the period 1970–2000 [2], the main advancements in shale gas production appeared after the year 2000. Accordingly, while the share of shale gas in total gas supply was nearly 0% in 1990, this ratio rose to 20% in 2010 [16]. According to Energy Information Administration (EIA) [23], this ratio was 30% in 2011 and was 34% in 2012. Observing this sharp increase in shale gas production, one may claim that, in terms of today, the shale gas might be a prominent source of the natural gas supply of the US [18]. Besides, it is estimated that the US will be able to procure the required natural gas quantity during next 100 years at current consumption rates via shale gas production [2].

In the literature, two main advances are emphasized as the reasons of the boom in production of shale gas. The first one is that gas producers have improved drilling techniques much as a result of considerable investments [5,24]. The drilling techniques are defined as the techniques that were developed through the combination of horizontal drilling and hydraulic fracturing methods particularly expanded production capacity and that were utilized to explore new sources [2]. The cost of shale gas production has decreased in parallel with improvements in drilling techniques in the US. The cost of shale gas production in the US is lower than the cost of natural gas production in most of the world, and this might be the initiator for the increasing global attention on shale gas. The second reason of shale boom is the rapid increase in prices of natural gas and crude oil in the US due to the increase in demand for natural gas and crude oil and the decrease in supply of natural gas and crude oil during 2000s [10]. According to the EIA [23], the price of natural gas for residential consumers peaked at $13.89/thousand cubic feet in 2008. Similarly, the price of crude oil peaked in this period. For instance, while the price of crude oil was generally lower than 25$/barrel, it was $30/barrel, $60/barrel, and $100/barrel in 2003, 2005, and 2007, respectively, and exceeded $140/barrel in 2008 [2]. These progresses induced a boom in production of shale gas. Fig. 1 depicts production of natural gas from shale gas in the US during the period 2008.01–2013.12. The natural gas production from shales in the US, in terms of January 2008, January 2010, and, December 2013 are 234084, 406673, and, 1024749 million cubic feet, respectively. Thereby, Fig. 1 reveals sharp increases in shale gas supply in the US within relevant period.

Overall, this paper aims at examining the effects of shale gas revolution and shale gas production on industrial production in the US by employing monthly data from January 2008 to December 2013.

The contribution of this paper is threefold: First, in the energy economics literature, papers examining the impact of energy production and/or consumption on economic growth usually follow either conventional energy sources (such as coal, oil, and natural gas) or electricity generation produced from conventional sources. Due to searches for alternative energy sources and technological development, unconventional energy sources (such as shale gas and shale oil) have gained importance and have substantially been utilized in recent years. Within this outlook, when one examines the energy economics literature, he/she will observe that there exists a research gap about the relationships between unconventional energy sources and economic growth. To the best of our knowledge, this is the first paper exploring the energy-growth nexus within the framework of unconventional energy sources. Hence this paper aims at filling the relevant gap of the literature by

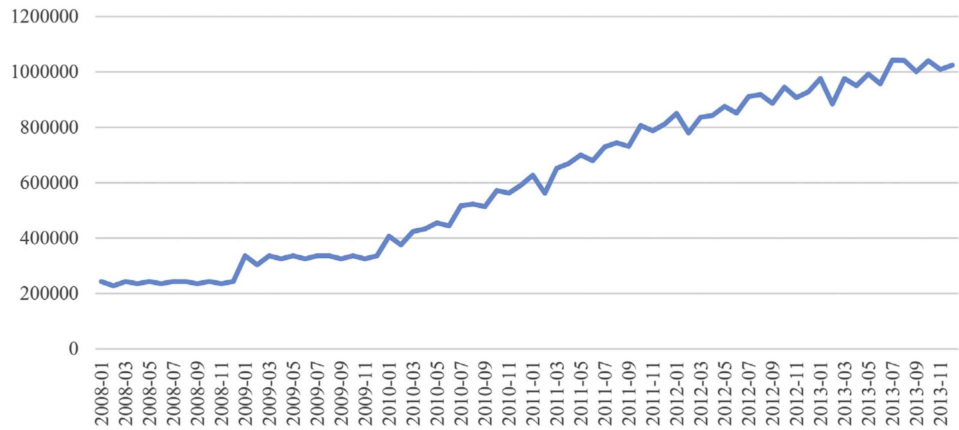

Fig. 1. US natural gas gross withdrawals from shale gas (million cubic feet), 2008.01–2013.12.
Source: EIA [25].

following shale gas energy-growth association.

Second, shale gas is evaluated as a new energy revolution of the US. Technological developments in respect of extracting shale gas are the main source of this revolution. The production of shale gas requires more technology use than that of conventional energy does. Thereby, producing shale gas is actually considered an improvement in technological level. However, there is limited information about the impacts of this revolution and technological development. Wang et al. [2] denote that there exists a research gap in the literature on the evolution and effects of the shale gas revolution in the US. Therefore, this paper may claim that it is essential to investigate the effects of shale gas on GDP/industrial production. In addition, this paper might argue that the findings obtained for the US might provide other countries with some important policy implications. Besides the US, some other countries (China, Argentina, Mexico, Algeria, Brazil, and Russia) also have high shale gas reserves (see Appendix A). However, these countries can't utilize shale gas as much as the US utilizes. With regard to EIA [26], China has the largest shale gas reserves in the world. Nevertheless, the share of natural gas production through shale gas in total natural gas production was lower than 1% in China by 2012. Therefore, findings of this paper might provide the US (and other countries that have rich shale gas reserves) with some energy management policy implications regarding energy supply/demand, energy efficiency, and energy technologies.

The third possible contribution of this paper is the methodology employed within its research. One might claim that available energy papers in the literature conduct, in general, standard test to observe the impulse of a conventional energy source on relevant macro variables. Standard cointegration tests, such as Engle and Granger [27] and Johansen [28,29], on the other hand, may exhibit biased and inconsistent estimators since they do not contemplate structural changes. However, when one or more structural breaks occur in the relationship between series (because of wars, natural disasters, and radical changes in economic policy etc.), these tests may not yield unbiased, consistent, and efficient results. In other words, in case there are available, indeed, one or more structural shifts, instead of traditional cointegration tests, the cointegration tests with structural breaks would be appropriate [30]. Thereby, Gregory and Hansen [31] and Westerlund and Edgerton [30] suggest cointegration tests allowing for structural breaks and/or regime shifts. While these tests assume a single break, Hatemi-J [32] propounds a cointegration test considering two breaks. Additionally, Maki [33] produces a relatively new cointegration test considering up to five different structural break points in relevant time horizon. As known, the US economy has experienced some extraordinary financial and/or industrial events since 2007. The subprime mortgage crisis that began in the US financial markets in 2007 became a global crisis on September 2008 allied to the bankruptcy of Lehman Brothers. Then, the US treasury started to implement expansionary fiscal policies to stimulate the economy. Besides, from December 2008 to October 2014, the Federal Reserve (FED) launched three quantitative easing programs (large-scale asset purchases) to boost the economic activities. In addition to developments in the US economy, the Euro Area commenced to experience a sovereign debt crisis beginning from summer 2011, and so the European Central Bank (ECB) enforced quantitative easing programs as implemented by the FED. All these monetary and fiscal advancements of course have affected the US economy. Thereby, this work employs Maki [33] cointegration analyses, as well as Carrion-i-Silvestre et al. [34] stationarity analyses, to be able to track such unforeseen serious financial, industrial, and political fluctuations.

Within the frame of this paper's indicated purpose, the rest of the paper is as follows: Section 2 presents the economic effects of shale gas production in the US. Empirical literature of the nexus between energy consumption, growth and/or CO_2 emissions is given in Section 3. Section 4 reveals relevant model, data, and estimation methodology. Section 5 reports estimation results, Section 6 yields a summary of the findings, and, Section 7 emphasizes some relevant policy implications.

2. Effects of shale gas production in the US economy

The literature accentuates mainly four aspects of the boom in shale gas production. The first one focuses on the effect of the boom on energy independence policies. After the oil crisis in 1970s, one of the most substantial goals of the US was to reach energy independency. Nearly 10 years ago, Dweck et al. [35] remarked that the US and Canadian gas reserves had begun to decline recently. However, the boom in shale gas production compensated this decline, decreased natural gas import volumes of the US on an unprecedented scale, and the natural gas import volumes in 2013 reached to the level in 1995. Fig. 2 shows the trend of natural gas import volumes of the US.

The second important effect of shale gas production in the US economy is the impact of shale gas production on natural gas prices. Energy prices are expected to increase as long as energy demand increases all over the world in general. However, natural gas price in the US began to decrease along with increasing shale gas

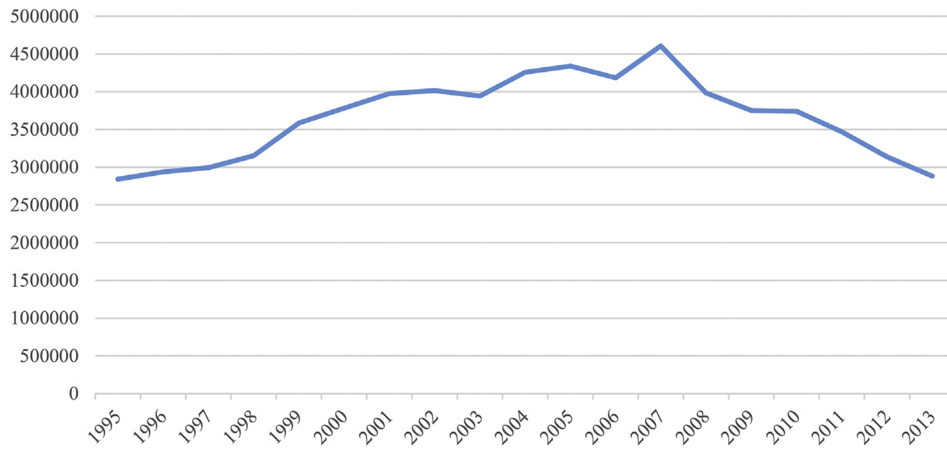

Fig. 2. US natural gas import volumes (million cubic feet), 1995–2014.
Source: EIA [36].

production beginning from 2008. Fig. 3 depicts the tendency of US natural gas prices for the period 1997–2014. When the increase in natural gas consumption is taken into account in the last decade, the reason of the decrease in natural gas prices appears to be the boom in shale gas production [19]. According to a report by Cambridge Energy Research Associates (CERA) [37], the main economic benefit of the shale gas revolution is the sharp decline in natural gas prices. During the period 2008–2013, (i) there exists a serious decline in natural gas prices, and (ii) natural gas prices in the US are three or four times lower than the prices that are determined by the contracts drawn up between the Russian Federation and Europe [20].

The third considerable effect of the increasing shale gas production in the US economy happens to the industrial sector. Increasing gas production and decreasing prices cause rises in gas demand of industrial producers as well as rises in purchasing powers of consumers [17]. As industrial producers' demand for natural gas is supplied more cheaply due to the increase in shale gas production, the shale production might be stimulated and, thus, employment might be affected positively in the US. Wang et al. [2] remark that the shale industry supports more than 600.000 jobs indirectly. It is predicted that this figure will reach 1.6 million in 2035. Low gas prices contribute to the competitiveness advantage of the chemical industry in the US [7]. Shale gas production results in the use of natural gas-based raw material instead of oil-based raw material in the chemical industry of the US unlike in chemical industries of other countries, and thus the chemical industry of the US obtains a price advantage over those of other countries [2].

The fourth crucial effect of shale gas in the US is an evidence to emerge which supports the green environment by diminishing CO_2 emissions. Shale gas is basically natural gas and cleaner than other fossil energies such as coal and oil [18]. Therefore, substitution of coal and oil with shale gas may lower CO_2 emissions markedly [19]. The US represents a very good example on this issue. In the US, according to EIA [39], the share of coal in electricity production was 52% in 2003. As known, coal is a pollutant fuel because of high carbon density [40]. Hence coal is a considerable pollutant leading to high carbon emissions. However, the US has begun to substitute coal with shale gas for electricity production in recent times [2,22], and thereby, the share of coal in electricity production fell to 40% in 2013 based on EIA [39], and thus, the CO_2 emissions of the US began to diminish. Wang et al. [9] assert that fossil fuel-based CO_2 emissions decreased by 430 million tons during 2006–2011 in the US. This decline has been the greatest decrease all over the world. The main reason of this development, most likely, stems from the production of shale gas in the US.

One may claim at this point, as well, that, apart from all its relevant economic and environmental benefits, the rapid increase in shale gas production may bring about some environmental concerns, since (i) hydraulic fracturing method employing water

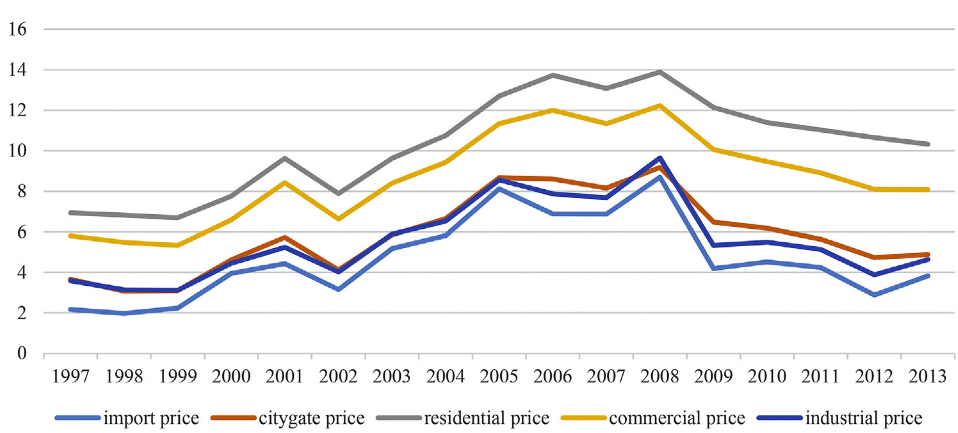

Fig. 3. US natural gas prices (dollars per thousand cubic feet), 1997–2014.
Source: EIA [38].

intensively may cause marine pollution, and (ii) great amounts of methane might be emitted during shale gas exploration and production [2]. Nonetheless, the environmental impacts of shale gas are limited in terms of global warming and marine pollution compared with environmental effects of coal. Jenner and Lamadrid [10] compare shale gas with coal. Firstly, CO_2 is the main greenhouse gas in the troposphere which needs roughly 100 years to disappear while methane dissolves within 12 years. Secondly, the footprint of shale gas is greater than that of natural gas while it is smaller than that of coal. Thirdly, less water is required to extract shale gas compared with coal. Even though these advantages of shale gas compared with coal, developing new technologies is essential in shale gas exploration to diminish current level of climate change and global warming problems.

3. Literature review on energy, growth and emissions nexus

In this section, this paper examines the available works observing (i) relationship between energy consumption and CO_2 emissions, (ii) the linkage of energy consumption to GDP growth, and (iii) projections and forecasts about the relationship between energy consumption and CO_2 emissions and/or economic growth under three groups. To do so, we intend to review the related energy literature intensively and to investigate specifically the papers covering the topic of shale gas energy and economic growth.

One may divide the related literature into three groups. The first group consists of some recent seminal papers that analyze the effects of energy consumption on CO_2 emissions. Saboori and Sulaiman [41] examine the relationship between CO_2 emissions and energy consumption in the selected Association of Southeast Asian Nations (ASEAN) countries for the period 1971–2009 by performing autoregressive distributed lag (ARDL) method. The findings of the paper indicate that CO_2 emissions are positively related to energy consumption. Kivyiro and Arminen [42] consider the connection between CO_2 emissions and energy consumption in six Sub Saharan African countries using data covering the period 1971–2009. According to the findings, CO_2 emissions are positively associated with energy consumption in two countries while CO_2 emissions are negatively accompanied by CO_2 emissions in one country. Salahuddin and Gow [43] explore the impact of energy consumption on CO_2 emissions in Gulf Cooperation Council (GCC) countries by employing pooled mean group (PMG) estimator for the period 1980–2012. They yield that energy consumption boosts CO_2 emission in these countries. Bilgili et al. [44], following data for 17 OECD countries over the period 1977–2010, analyze the effects of renewable energy consumption on CO_2 emissions by performing panel fully modified ordinary least squares (FMOLS) and panel dynamic ordinary least squares (DOLS) estimators. The output of this paper exhibits that an expansion of renewable energy consumption might lead to mitigation in CO_2 emissions in related countries.

The second group comprises several prominent papers launching some econometric models and/or projections on the link between energy consumption and CO_2 emissions and/or growth. Forecasting future energy consumption and/or CO_2 emissions is considerable to determine energy, environmental, and technology policies [50–53]. Say and Yucel [54] investigate the liaison among economic growth, energy consumption and CO_2 emissions. They reveal significant effect of population and GDP on total energy consumption. Later, they yield that an 8.4% increase in energy consumption is expected to increase the CO_2 emissions by 9.9% yearly in average. Kone and Buke [55] forecast the trend of fossil-fuel based CO_2 emissions in top 25 countries with the highest CO_2 emissions. They yield that statistically significant trends are found in eleven countries (Australia, Brazil, India, Indonesia, Islamic Republic of Iran, Mexico, Saudi Arabia, South Africa, South Korea, Taiwan, and Turkey). Feng and Zhang [56] run some simulations on the effects of alternative development indicators on the future energy consumption and CO_2 emissions through A Long-range Energy Alternatives Planning (LEAP) in Beijing. They employ three scenarios: The scenarios are business-as-usual (BAU), basic-policy (BP), and low-carbon (LC), respectively. The results show that, in the LC scenario, total energy consumption in Beijing is expected to reach 88.61 million metric tons coal equivalent (Mtce) by 2030. This estimation of energy demand under LC scenario is 55.82% and 37.72% lower than those of the BAU and BP scenarios, respectively. Besides, the total CO_2 emissions in 2030 with the LC scenario will be 62.22% and 36.75% lower than those in BAU and BP scenarios, respectively. Additionally, under the LC scenario, clean and efficient energy will account for 58% of total energy consumption of Beijing in 2030. This result is 17% and 12% higher than those of the BAU and LP scenarios, respectively. Aydin [57] foresees the effects of primary energy consumption on GDP and population through three scenarios over the period 2010–2025. In the paper, Turkey's primary energy consumption is anticipated under different scenarios through various assumptions considering the different growth rates of population and GDP for each scenario. The findings show that the proposed model can be effectively employed to forecast the primary energy consumption of Turkey. The scenarios also indicate that the future energy consumption of Turkey would vary between 174.65 and 203.13 Mtoe in 2025. Aydin [58], considering the main indicators affecting energy-related CO_2 emissions, yields that the proposed model in the paper can be employed to project energy-related CO_2 emissions for Turkey. Aydin [59], additionally, determines the path of coal-based CO_2 emissions for countries and regions with the highest CO_2 emissions over the period 1971–2010. In this work, statistically significant trends are found for (a) the world total, (b) the regions of OECD Americas, OECD Asia Oceania, Africa, Asia, China, and, non-OECD Americas, and (c) the countries of the US, India, Japan, South Africa, South Korea, Australia, Chinese Taipei, Turkey, and Indonesia. Aydin [60] forecasts, as well, the trend of global oil and natural gas production over the period 1985–2010. The results reveal that the proposed models in this paper can be followed efficiently to anticipate the future oil and natural gas production within the relevant countries. Finally, Aydin [61] explores that the model used in the paper can be utilized to project primary energy consumption by the sources for future planning.

Table 1 reveals the summary of output of some papers that appear in the first and second groups above. One may remark, upon the outcome of Table 1, that the projections and/or regression convergence analyses through singe or the multiple variables in the literature do not employ any possible effects of shale gas on an economy.

In the third group, one may observe the papers searching specifically the relationships between energy consumption and GDP through some econometric methods. Kraft and Kraft [45] might be considered the pioneer work on this topic. They investigate the causal relationships between energy consumption and GDP for the US over the period 1947–1974 through the causality analyses. According to the findings of the paper, there is a unidirectional causal relationship running from GDP to energy consumption.

After the work of Kraft and Kraft [45], the succeeding papers investigating energy-growth nexus has become an essential field of interest in economics [46] since they have potential remarks to guide the policy makers in designing energy policies.

Shiu and Lam [47] consider the tie between electricity consumption and GDP in China for the period 1971–2000 by performing cointegration and Granger causality analyses based on vector error correction model (VECM). Their evidence explores that

Table 1
Some seminal projections on energy, and/or growth, and/or emissions.

Author(s)	Country/Period	Methodology	Variables	Output
Craig et al. [50]	USA F: 2000–2020	Forecast	ec, gw	Long term predictions
Utgikar and Scott [51]	Participants 1985–2000	Delphi technique	nec, fec, rec, et	Suggestions for improving the accuracy of forecast
Azadeh and Tarverdian [52]	Iran 1991:3–2005:2	Integrated algorithm	ec	Comparisons of GA and time series' forecast accuracy
Khatib [53]	World 1990–2008	Scenario projections	ec, gdp, co_2	Great moderations in ec and co_2 by 2035 through efficiency
Say and Yucel [54]	Turkey 1970–2002	Regression analyses	ec, gnp, pop	Prominent response of ec to gnp and pop
Kone and Buke [55]	11 countries and World 1970–2010	Trend analyses	ec, fec, co_2	Positive impacts of ec and fe on co_2
Feng and Zang [56]	China 2007–2030	Scenario analyses	ec, co2	The domination of clean and efficient energy by 2030
Aydın [57]	Turkey 1971–2010	Regression analyses	pec, pop, gdp	The significances of pop, gdp, gov and clmt on pec forecasting
Aydın [58]	Turkey 1971–2010	Correlation analyses and Multiple linear regressions	pop, anec, gdp, crwc, fec, co_2	The significant influences of pop, fec and gdp on co_2
Aydın [59]	7 regions, 9 countries and World 1971–2010	Regression analyses and projections	$crco_2$	The success of the projections to predict future $crco_2$ trends
Aydın [60]	World 1985–2010	Trend analyses	oil, ng	The accuracies of trend models to forecast future oil and ng
Saboori and Sulaiman [41]	ASEAN 1971–2009	Cointegration and Causality	ec, gdp co_2	The nonlinear causality between co_2 and gdp in Singapore and Thailand
Saboori and Sulaiman [41]	ASEAN 1971–2009	Cointegration and causality	ec, gdp, co_2	Bi-directional causality in ASEAN countries
Kivviroa and Arminen [42]	Sub-Saharan Countries 1971–2009	Cointegration and causality	ec, gdp, fdi, co_2	The significant impacts of ec, gdp and fdi on co_2
Salahuddin and Gow [43]	GCC countries 1980–2012	Cointegration	ec, gdp, co_2	Positive relationship between ec and co_2
Salahuddin and Gow [43]	GCC countries 1980–2012	Cointegration	ec, gdp, co_2	No relationship between gdp and co_2
Bilgili, Koçak and Bulut [44]	17 OECD Countries 1977–2010	FMOLS, DOLS	gdp, gdp^2, co_2, rec	Negative impact of rec on co_2
Bilgili, Koçak and Bulut [44]	17 OECD Countries 1977–2010	FMOLS, DOLS	gdp, gdp^2, co_2, rec	EKC holds and does not depend on income level of the countries

Note: F: Forecast, EC: energy consumption, GW: Global Warming, NEC: Nuclear energy consumption, FEC: Fossil energy consumption, REC: Renewable energy consumption, ET: Energy transmission, GDP: Gross domestic product, CO2: Carbon dioxide emissions, POP: Population, GNP: Gross national product, GOV: Government policies, CLMT: Climate changes, PEC: Primary energy consumption, ANEC: Alternative and nuclear energy consumption, CRWC: Combustible renewables and waste energy consumption, $CRCO_2$: Coal related CO_2 emissions, OIL: Oil production, NG: Natural gas production, FDI: Foreign direct investment, GDP^2: GDP squared, EKC: Environmental Kuznets Curve.

there exists unidirectional causality from electricity consumption to GDP. Paul and Bhattacharya [48] view the linkage of energy consumption to GDP for India over the period 1950–1996 by conducting cointegration and causality analyses. According to the findings of the paper, bidirectional causality exists between energy consumption and GDP in India. Sari et al. [49], using the data covering the period 2001–2005 and employing ARDL method, consider the relationships among disaggregate energy consumption, industrial production, and employment in the US. The evidence of the paper implies that industrial production and employment are long run determinant variables for almost all types of disaggregate energy consumption.

Besides the seminal papers investigated above, one might pursue, as well, the available works to review the literature outcome with respect to relevant four hypotheses to test energy-growth nexus.

Table 2 depicts some seminal studies on energy consumption-economic growth nexus in the literature. These studies in the literature differ from each other in terms of countries, time periods, variables, and econometric methods [62]. The relationships between different types of energy and growth are investigated by mainly employing cointegration and/or causality analyses in the literature. There are four hypotheses to test energy-growth relationships. The first hypothesis considers if there is unidirectional causality from energy consumption to growth. When this hypothesis is valid, one may claim that energy saving policies or energy supply shocks may affect economic growth negatively. The second one is the conservation hypothesis which is relevant to argument about if there occurs unidirectional causality from economic growth to energy consumption. In other words, economic growth leads to an increase in energy consumption. When this hypothesis is valid, one may state that energy saving policies don't affect economic growth negatively. The third one is the neutrality hypothesis, and this hypothesis indicates there is no causal relationship between energy consumption and economic growth. The validity of this hypothesis means that energy policies have very limited effects or do not have any influence on economic growth. The last one is the feedback hypothesis pertaining to observe if there happens to be bidirectional causality between energy consumption and economic growth. When this hypothesis is effectual, one can assert that energy saving policies may affect economic growth negatively and this negative effect, in turn, might be reflected to energy consumption.

When Table 2 is examined, one observes that the energy-GDP nexus is investigated within the dimension of conventional energy sources. However, our paper considers shale gas that is an unconventional energy source unlike other papers do. Within this framework, this paper aims at exploring the relationship between aggregate shale gas production and industrial production to fill the gap in the energy economics literature. Therefore, as far as we know, our paper is the first work that examines the causality from shale gas production to industrial production in terms of the aggregated level of the US economy. On the other hand, there are some other papers studying the economic effects of shale gas production at the disaggregated (state) level of the US.

For instance, Considine et al. [84] consider the economic effects of the Marcellus Shale gas extraction operations in West and North Pennsylvania through IMPLAN input-output models. They yield

Table 2
Some seminal empirical studies on energy-growth nexus.

Author(s)	Country/Period	Methodology	Variables	Conclusion(s)
Kraft and Kraft [45]	USA 1947–1974	Causality	ec, gdp	Conservation
Eden and Jin [63]	USA 1974–1990	Cointegration and causality	ec, gdp	Cointegration and neutrality
Ghosh [64]	India 1950–1997	Cointegration and causality	elec, gdp	Cointegration and nonservation
Oh and Lee [65]	Korea 1970–1999	Cointegration and causality	ec, gdp	Cointegration and feedback
Yoo [66]	Korea 1970–2002	Cointegration and causality	elec, gdp	Cointegration and feedback
Ang [67]	Fransa 1960–2000	Cointegration and causality	ec, gdp	Cointegration and growth
Narayan and Smyth [68]	G7 1972–2002	Cointegration and causality	K, L, ec, gdp	Cointegration and growth
Reynolds and Kolodziej [69]	Soviet Union 1987–1996	Causality	oilp, coalp, ngp, gdp	Conservation (oil) and growth (ngp, coalp)
Payne [70]	USA 1949–2006	Causality	rec, nrec, gdp	neutrality
Akinlo [71]	Nigeria 1980–2006	Cointegration and causality	elec, gdp	Cointegration and growth
Abosedra et al. [72]	Lebanon 1995–2005	Causality	elec, gdp	Growth
Payne and Taylor [73]	USA 1957–2006	Causality	nec, gdp	Neutrality
Apergis and Payne [74]	25 OECD countries 1980–2005	Cointegration and causality	coalc, gdp	Cointegration and feedback
Apergis and Payne [75]	67 countries 1992–2005	Cointegration and causality	K, L, ngc, gdp	Cointegration and feedback
Menegaki [76]	27 European countries 1997–2007	Random effects model	rec, gdp	Neutrality
Shahbaz et al. [77]	Pakistan 1972–2011	Cointegration and causality	K, L, rec, nrec, gdp	Cointegration and feedback
Dagher and Yacoubian [46]	Lebanon 1980–2009	Cointegration and causality	ec, gdp	Cointegration and feedback
Ocal et al. [78]	Turkey 1980–2006	Causality	K, L, ec, gdp	Neutrality
Ocal and Aslan [79]	Turkey 1990–2010	Causality	rec, gdp	Conservation
Nasreen and Anwar [80]	15Asian 1980–2011	Cointegration and causality	ec, gdp, opp	Cointegration and feedback
Park and Yoo [81]	Malaysia 1965–2011	Cointegration and causality	oil, gdp	Cointegration and feedback
Lin and Moubarak [82]	China 1977–2011	Cointegration and causality	rec, gdp	Cointegration and feedback
Ozturk and Bilgili [83]	50 African 1980–2009	Cointegration	bio, gdp opp, pop	Cointegration

Note: EC: Energy consumption, ELEC: Electricity consumption, GDP: Gross domestic product, K: Capital, L: Labor, NEC: Nuclear energy consumption, REC: Renewable energy consumption, NREC: Non-renewable energy consumption, NGC: Natural gas consumption, OILP: Oil production, COALC: Coal consumption, COALP: Coal production, NGP: Natural gas production, BIO: Biomass consumption, OPP: Openness, POP: Population.

that the shale gas industry created about 29000 jobs and 238 million US tax incomes and that shale gas production accounted for about 2.2 billion USD of the economic activities.

Paredes et al. [85] investigate the impulses of the shale gas extraction operations on income and production in the Marcellus region. They reach that the shale gas extraction operations do not have significant effects on income and production.

Munasib and Rickman [86] examine the effects of shale gas and shale oil production on total employment, wage and salary employment, income per capita, the poverty rate, and population in Arkansas, North Dakota, and Pennsylvania by conducting the synthetic control analysis. They found (i) significant positive effects for the oil and gas counties in North Dakota, and, (ii) significant positive effects in Arkansas for the counties which are intensive in shale gas production. On the other hand, they reveal no statistically significant positive effects of relevant variables in Pennsylvania.

Lee [87], using data covering the period 2009–2014 for Texas, considers the effects of shale gas and shale oil extraction operations on employment and income at the local level and finds that shale gas extraction operations have greater effects than shale oil extraction operations do. Hartley et al. [88], using data for the period 2001–2011 and employing a panel econometric model, estimate the historical job-creating performance of wind versus that of shale oil and gas. According to their outcome, shale related activities have brought strong employment to Texas. For example, based on the 5482 new directional/fractured wells drilled in Texas in 2011, the estimates imply that between 25,000 and 125,000 net jobs were created in that year alone [88].

Eventually, one may notice that the literature of energy summarized in Tables 1 and 2 does not reveal any evidence on the significance of shale gas production in a national economy.

After reviewing the literature review, the motivation and contribution of this paper to the energy literature can be summarized as follows.

- First, this work reviews intensively the existing literature in order to (a) observe the nexus of total energy consumption, GDP and/or CO_2 emissions, and, (b) see explicitly which theoretical and/or statistical evidence of shale gas' impact on the US economy is available in the related energy field.
- Secondly, this research launches particular econometric models to measure the impact of shale gas on the US energy markets. The paper, hence, considers possible structural breaks of the US economy before it estimates the impact of shale gas revolution on the US GDP level through monthly observations. In case it is found a significant response of US GDP to the intensive shale production, one might claim implicitly, as well, that energy investment opportunities, and, hence, employment level of the US will have increased through shale gas exploration in the US.

4. Model, data, and estimation methodology

As was explained previously in the text, one of the purposes of this paper, after following an intensive energy literature, is to launch an empirical model to expose the relationship of US GDP data with the data for US shale gas production. Thus, this section will introduce data, the model and the tests through relevant equations. All equations are mainly derived from the methodologies of [33,34,99,100,101]. All regarding equations and estimations aim at providing potential reader with (i) information about tests, (ii) explanation why these tests differ from other conventional tests, and, (iii) estimation output observing structural breaks of the US. Without tracking possible structural financial/industrial/political breaks in the US, any model estimating the nexus between shale gas and the US GDP would yield inconsistent and biased statistical results, hence, would not explore most likely the efficient and reliable policy proposals for the US and for other possible countries' administrators. Therefore, Section 4.1 presents the model to be estimated, Section 4.2 comprises the methodologies of unit root, cointegration and causality tests. All tests are conducted by evaluating potential structural shifts in the US economy.

4.1. Model and data

As was explained in previous sections, the influence of an energy production/consumption on a national economy is an important issue, and, hence, this issue has been investigated by many seminal papers in the literature of energy and/or energy economics. Nevertheless, none of these articles searched the nexus between shale gas, a non-conventional energy, and commodity markets of a national economy.

We, thereby, particularly want to focus on uncommon upward movements of shale gas production together with the upward trend in the US commodity markets (represented by industrial production) since there exists no empirical evidence to show how these extraordinary movements in shale gas (shale gas revolution) affected the US economy (US industrial production index) for the period 2008:1–2013:12. To do so, we launch some advanced time series models in which we can expose the potential impacts of shale gas revolution on the US industrial production.

Before depicting the models and their output, one might need to observe the some preliminary indicators such as mean values and growth rates of energy resources and industrial production in the US through sub periods 2008:1–2009:12, 2010:1–2011:12 and 2012:1–2013:12.

Below Fig. 4 explores the means of oil, coal, renewables and shale gas and Fig. 5 exhibits the average values of industrial production in the US. There exists, except coal production, an increase in the production of oil, renewables and shale gas and there is an increment in industrial production through relevant sub periods. Fig. 4 yields that the sharpest increase happens to be in production of shale gas among other energy resources. This might be a preliminary indicator in this research to reveal the outstanding augmentation volume of shale gas that, most likely, might have arisen from shale gas revolution in the US for the period 2008:1–2013:12. From 2008:1 to 2013:12, the growth rates of oil, coal, renewable, and shale gas are 34.52%, -10.92%, 22.20%, and, 386.87%, respectively. The growth rate of the industrial production index for the same period is 5.79%.

The energy resources' data are obtained from EIA [23,26] and industrial production data are extracted from US Federal Reserve [89].

The purpose of this research, hence, aims at observing the response parameters of industrial production to the outstanding changes in shale gas production in the US. Fig. 6 depicts the graphical observations of logarithmic forms of industrial production (lnIP) and shale gas production (lnSHALE) variables and it shows the movements and co-movements between these variables.

Fig. 6, thereby, reveals the simultaneous fluctuations of lnSHALE and lnIP in the US. Therefore, Fig. 6 aims at providing a researcher with information about trends, co-movements and discrepancies between lnSHALE and lnIP. The variable of lnSHALE is estimated well by the polynomial equation of $y = 2E\text{-}07x^4 - 3E\text{-}05x^3 + 0{,}002x^2 - 0{,}0101x + 12{,}388$ and the variable of lnIP is depicted well by polynomial equation of y = 9E-08x4 - 2E-05x3 + 0,0011x2 - 0,0274x + 4,6839. One may observe that the series of lnSHALE yields relatively more severe picks and troughs than lnIP does.

As is seen in Fig. 6, there is a decline in industrial production from January 2008 to June 2009 because of the global crisis. Beginning from the second half of 2009, there appears a co-movement between the series and the relevant series have a tendency to increase.

Descriptive statistics and correlation matrix of related variables are also presented in Table 3. One notes that the all descriptive statistics of lnIP are lower than those of lnSHALE. One may notice, as well, that there is a positive correlation between lnIP and lnSHALE.

Graphical observations and descriptive statistics are of course to provide one with some initial and/or preliminary inspection. However, beyond graphical/basic statistical analyses, one may need to consider, as well, some advanced econometric methodologies to observe the long run relationship through unit root, cointegration and causality estimations to obtain unbiased and efficient output.

By following advanced econometric approaches, the model in this research, hence, aims at inspecting the possible short run and long run impulses of considerable changes in lnSHALE on lnIP. In order to examine the impact of natural gas production from shale gas wells on industrial production in the US, this paper employs the function as follows:

$$lnIP_t = \beta_0 + \beta_1 lnSHALE_t + \varepsilon_t \tag{1}$$

where $lnIP_t$ denotes the logarithmic form of seasonally adjusted total industrial production index (2012 = 100), $lnSHALE_t$ represents the logarithmic form of seasonally adjusted natural gas production from shale gas in million cubic feet, and ε_t depicts error term, respectively. The data are monthly and cover the period 2008:01–2013:12.

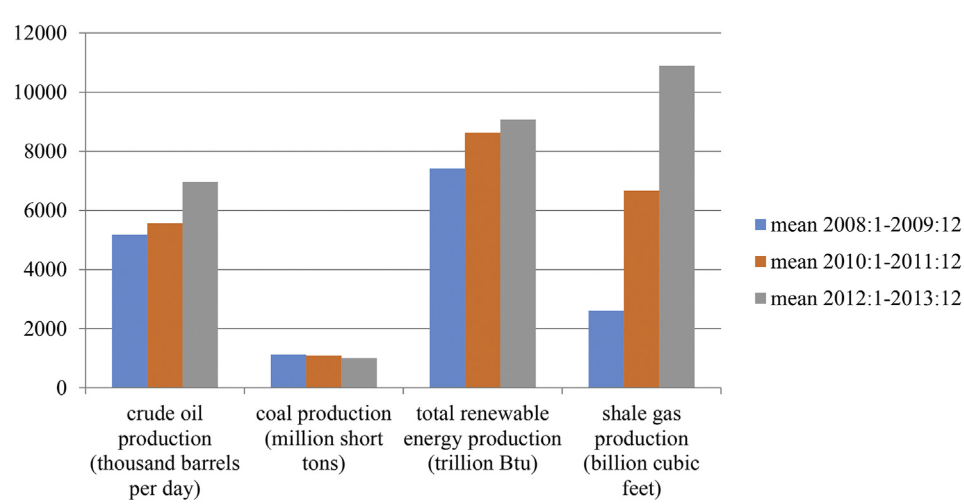

Fig. 4. Oil, coal, renewables and shale gas production, 2008:01–2013:12.
Source: EIA [23].

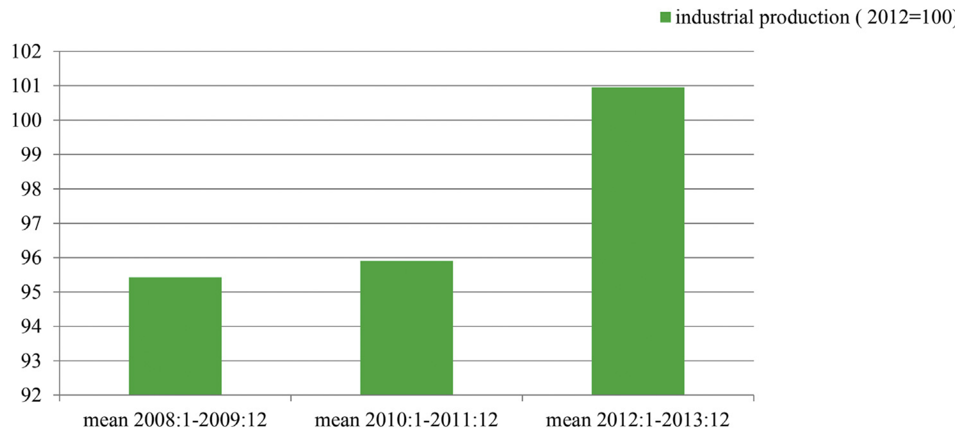

Fig. 5. Industrial production index, 2008:01–2013:12.
Source: Federal Reserve [89].

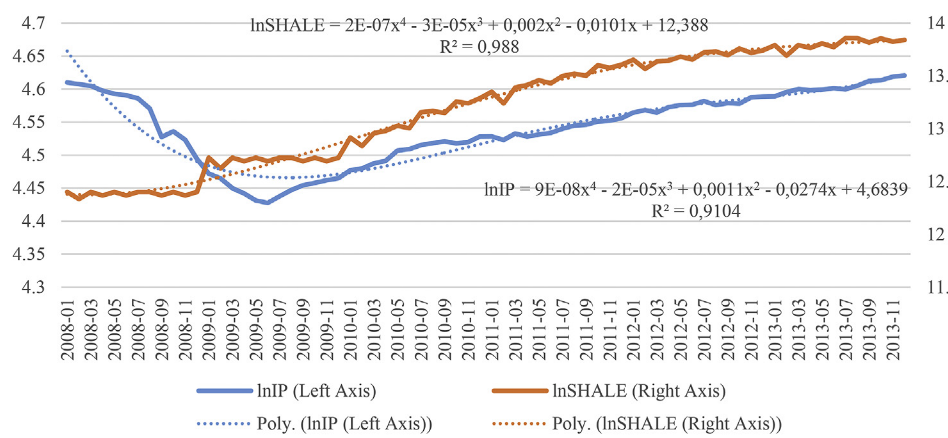

Fig. 6. The trends of lnIP and lnSHALE, 2008:01–2013:12.
Source: EIA [23,26], US Federal Reserve [89].

Table 3
Descriptive statistics and correlation matrix for lnIP and lnSHALE, 2008:01–2013:12.

	lnIP	lnSHALE
Descriptive statistics		
Mean	4.54	13.18
Median	4.54	13.28
Maximum	4.62	13.84
Minimum	4.42	12.27
Std. deviation	0.05	0.52
Observations	72	72
Correlation matrix		
lnIP		0.48
lnSHALE	0.48	

4.2. Estimation methodology

4.2.1. Unit root tests

Specifying the order of integration of variables is the first step in time series analyses since one may experience spurious regression problem when regarding analyses employ conventional ordinary least squares (OLS) estimations.

Unit root tests developed by Dickey and Fuller ([90], hereafter ADF) and Phillips and Perron ([91], hereafter PP) are commonly utilized in econometrics literature. The main shortcoming of these tests is that they do not take into account possible structural breaks in series. However, series may have structural breaks, and hence, convergence analyses should examine simultaneously the long term parameters and structural shift parameters.

Carrion-i-Silvestre et al. [34] develop a unit root testing procedure by (i) allowing for an arbitrary number of changes in level and the slope of the trend function, (ii) adopting the so-called quasi-generalized least squares (quasi-GLS) detrending method suggested by Elliott et al. [92], (iii) considering a variety of tests, in particular the class of M-tests. The testing procedure of Elliott et al. [92] observes if local asymptotic power functions close to the local asymptotic Gaussian power envelope. M tests are introduced in Stock [93] and analyzed in Ng and Perron [94].

Carrion-i-Silvestre et al. [34] assert that simulation experiments justify that their procedures offer improvements over commonly used methods in small samples. Therefore, this paper will perform the quasi-GLS unit root tests by Carrion-i-Silvestre et al. [34] for the series employed in this paper. Carrion-i-Silvestre et al. [34] obtain structural break points using the algorithm of Bai and Perron [95] through quasi-GLS method and dynamic programming process minimizing sum of squared residuals. Let y_t be a stochastic process generated according to

$$y_t = d_t + u_t \tag{2}$$

$$u_t = \alpha u_{t-1} + \upsilon_t, \quad t = 0, \ldots, T \tag{3}$$

where $\{u_t\}$ is an unobserved mean-zero process assuming that

$u_0 = 0$, though the results generally hold for the weaker requirement that $E(u_0^2) < \infty$. The disturbance term υ_t is defined by $\upsilon_t = \sum_{i=0}^{\infty}\gamma_i\eta_{t-i}$ with $\sum_{i=0}^{\infty} i|\gamma_i| < \infty$ and $\{\eta_t\}$ a martingale difference sequence adapted to the filtration $F_t = \sigma$-field$\{\eta_{t-i};\, i \geq 0\}$. The long-run and short-run variance as $\sigma^2 = \sigma_\eta^2\gamma(1)^2$ and $\sigma_\eta^2 = \lim_{T\to\infty} T^{-1}\sum_{t=1}^{T}E(\eta_t^2)$, respectively. Carrion-i-Silvestre et al. [34] generate five test statistics to test for the null hypothesis for a unit root under multiple structural breaks. The first one is as follows:

$$P_T^{GLS}\left(\lambda^0\right) = \left\{S\left(\overline{\alpha},\, \lambda^0\right) - \overline{\alpha}S\left(1,\, \lambda^0\right)\right\} / s^2\left(\lambda^0\right) \tag{4}$$

where P_T^{GLS} denotes the feasible optimal statistic, λ^0 gives the estimate of the vector of break fractions, and $s^2(\lambda^0)$ yields an estimate of the spectral density at frequency zero of υ_t, Following Ng and Perron [94] and Perron and Ng [96], Carrion-i-Silvestre et al. [34] consider an autoregressive estimation defined in Equation (5).

$$s\left(\lambda^0\right)^2 = s_{ek}^2 / \left(1 - \sum_{j=1}^{k}\widehat{b}_j\right)^2 \tag{5}$$

where $s_{ek}^2 = (T-k)^{-1}\sum_{t=k+1}^{T}\widehat{e}_{t,k}^2$ and $\{\widehat{b}_j, \widehat{e}_{t,k}\}$ obtained from the OLS regression as given in Equation (6).

$$\Delta\tilde{y}_t = b_0\tilde{y}_{t-1} + \sum_{j=1}^{k} b_j\Delta\tilde{y}_{t-j} + e_{t,k} \tag{6}$$

where $\tilde{y}_t = y_t - \widehat{\psi}' z_t(\lambda^0)$ as $\widehat{\psi}$ minimizes the objective function demonstrated as indicated in (7).

$$S^*\left(\psi, \overline{\alpha}, \lambda^0\right) = \sum_{t=1}^{T}\left(y_t^{\overline{\alpha}} - \psi' z_t^{\overline{\alpha}}\left(\lambda^0\right)\right)^2 \tag{7}$$

The order of the autoregression k term in Equation (5) is selected using the modified information criteria suggested by Ng and Perron [94] and modified by Perron and Qu [97].

Following Perron and Rodriguez [98], Carrion-i-Silvestre et al. [34] also use the M-class of tests analyzed in Ng and Perron [94] allowing for multiple structural breaks as given in Equations (8)–(10).

$$MZ_\alpha^{GLS}\left(\lambda^0\right) = \left(T^{-1}\tilde{y}_T^2 - s\left(\lambda^0\right)^2\right)\left(2T^{-2}\sum_{t=1}^{T}\tilde{y}_{t-1}^2\right)^{-1} \tag{8}$$

$$MSB^{GLS}\left(\lambda^0\right) = \left(s\left(\lambda^0\right)^{-2}T^{-2}\sum_{t=1}^{T}\tilde{y}_{t-1}^2\right)^{1/2} \tag{9}$$

$$MZ_t^{GLS}\left(\lambda^0\right) = \left(T^{-1}\tilde{y}_T^2 - s\left(\lambda^0\right)^2\right)\left(4s\left(\lambda^0\right)^2T^{-2}\sum_{t=1}^{T}\tilde{y}_{t-1}^2\right)^{-1/2} \tag{10}$$

as $\tilde{y}_t = y_t - \widehat{\psi}' z_t(\lambda^0)$, where $\widehat{\psi}$ minimizes Equation (7) and $s(\lambda^0)^2$ is defined in Equation (5). The next monitored statistic, following Ng and Perron [94], is a modified feasible point optimal test defined by Equation (11).

$$MP_T^{GLS}\left(\lambda^0\right) = \left[\overline{c}^2T^{-2}\sum_{t=1}^{T}\tilde{y}_{t-1}^2 + (1-\overline{c})T^{-1}\tilde{y}_T^2\right] \Big/ s\left(\lambda^0\right)^2 \tag{11}$$

Equation (11) is based on the same motivation that leads to the definition of the M-tests in Stock [93]. $MP_T^{GLS}(\lambda^0)$ is a crucial statistic because its limiting distribution coincides with that of the feasible point optimal test.

The asymptotic critical values are generated through bootstrap approach. If the calculated tests statistics are lower than critical values, the null hypothesis is rejected, and the rejection of the null hypothesis suggests the absence of a unit root in series [34].

4.2.2. Cointegration tests

After determining the order of integration of variables, the next step is to examine the cointegration relationship, if exists, among variables.

Engle and Granger [37] and Johansen [28,29] cointegration tests which are widely employed in econometric analyses do not track the structural break(s) in the series either. In the event there are one or more structural breaks, standard cointegration tests may not be convenient. Maki [33] produces a cointegration test that regards structural breaks up to five different points in time. Therefore, this paper will conduct, as well, Maki [33] cointegration test with some potential structural breaks. According to this cointegration test, every period in the sampling period is a possible breaking point and corresponding statistics are computed for each period. Then, the lowest t-statistics determine the break points of time series period.

When we launch some advanced time series models to estimate the parameters of independent variable (here, shale gas production) on dependent variable (here, industrial production), we need to consider below issues to distinguish our advanced econometric analyses from regular econometric analyses. In regular analyses, mostly, it is assumed that level, and/or, parameters, and/or trend of the model(s) will not change through time. However, the national economies, hence the relevant data, might subject to change from a sub period to another sub period due to some political, economic and/or social structural breaks that might occur within observed time horizon (here; 2008:1–2013:12).

These issues, that need to be considered, are:

(I) When there might exist a potential break in the constant of the model in which trend is not assumed to be present,
(II) When there might exist potential breaks in the constant, and, in the parameters of the model in which trend is not available,
(III) When there might exist potential breaks in the constant, and, in the parameters of the model where trend is available,
(IV) As potential breaks are present in the constant, and, in the parameters, and, in the trend of the model where trend is available.

These models are very essential to forecast the relevant coefficients of the models to reach best linear/nonlinear unbiased estimators. To this end, we employ Maki [33] cointegration test to follow the models of (I), (II), (III), and, (IV), instead of following regular econometric forecast in which coefficients are assumed to be fixed. Therefore, in this work, we attempt to consider possible structural changes and/or regime shifts in constant term, and/or, in parameters, in trend term through the estimations of a long run regression model. Otherwise, any model without considering these potential structural changes in an econometric model would yield inconsistent, biased and inefficient estimates.

Maki [33] considers the following regression models to test for possible cointegration relation for multiple breaks as given in Equations from (12) to (15).

Model (I):

$$y_t = \mu + \sum_{i=1}^{k} \mu_i D_{i,t} + \beta' x_t + u_t \quad (12)$$

Model (II):

$$y_t = \mu + \sum_{i=1}^{k} \mu_i D_{i,t} + \beta' x_t + \sum_{i=1}^{k} \beta_i' x_t D_{i,t} + u_t \quad (13)$$

Model (III):

$$y_t = \mu + \sum_{i=1}^{k} \mu_i D_{i,t} + \gamma t + \beta' x_t + \sum_{i=1}^{k} \beta_i' x_t D_{i,t} + u_t \quad (14)$$

Model (IV):

$$y_t = \mu + \sum_{i=1}^{k} \mu_i D_{i,t} + \gamma t + \sum_{i=1}^{k} \gamma_i t D_{i,t} + \beta' x_t + \sum_{i=1}^{k} \beta_i' x_t D_{i,t} + u_t \quad (15)$$

where t = 1,2, …,T. y_t and $x_t = (x_{1t},\ldots,x_{mt})'$ denote observable I(1) variables, and u_t is the equilibrium error, y_t is a scalar, and $x_t = (x_{1t},\ldots,x_{mt})'$ is an (mx1) vector. Maki [33] assumes that an (nx1) vector z_t is generated by $z_t = (z_t, x_t')' = z_{t-1} + \varepsilon_t$, where ε_t are i.i.d. with mean zero, positive definite variance-covariance matrix Σ, and $E|\varepsilon_t|^s < \infty$ for some $s > 4$. μ, μ_i, γ, γ_i, $\beta' = (\beta_1,\ldots,\beta_m)$, and $\beta_i' = (\beta_{i1},\ldots,\beta_{im})$ are true parameters. $D_{i,t}$ represents dummy variables taking a value of 1 if $t > T_{Bi}$ (i = 1, …,k) and of 0 otherwise, where k is the maximum number of breaks and T_{Bi} denotes the time period of break. Equation (12) has the model with level shifts. Equation (13) allows for structural breaks of level and regressors. Equation (14) extends Equation (13) with a trend. Equation (15) includes structural breaks of levels, trends, and regressors employed.

4.2.3. Estimation of long-term coefficients

When the cointegration relationship is obtained among variables, the following process is to estimate long-term coefficients through the dynamic ordinary least squares (DOLS) approach produced by Stock and Watson [99]. Stock and Watson [99] estimate a long-run dynamic equation that includes leads and lags of explanatory variables. This method corrects the possible endogeneity and serial correlation problems in the OLS estimation [100]. The DOLS model, then, can be written as indicated by Equation (16).

$$y_t = \alpha_0 + \alpha_1 t + \alpha_2 x_t + \sum_{i=-q}^{q} \delta_i \Delta x_{t-i} + \varepsilon_t \quad (16)$$

where y, t, x, q, Δ, and e represent dependent variable, time trend, independent variable, optimum leads and lags, difference operator, and error term, respectively.

4.2.4. Causality test

Though the Johansen [28,29] and Maki [33] cointegration tests show that there is a long-term relation between variables, it does not inform about the direction of Granger causality. Granger [101] argues that causal relations should be examined within the framework of vector error correction model (VECM) if variables are cointegrated. We can generate error correction models in which the causalities among Y and X are investigated as below:

$$\Delta Y_t = \alpha_0 + \sum_{i=1}^{m} \alpha_{1i} \Delta Y_{t-i} + \sum_{i=1}^{m} \alpha_{2i} \Delta X_{t-i} + \psi EC_{t-1} + e_{1t} \quad (17)$$

$$\Delta X_t = \beta_0 + \sum_{i=1}^{m} \beta_{1i} \Delta X_{t-i} + \sum_{i=1}^{m} \beta_{2i} \Delta Y_{t-i} + \Phi EC_{t-1} + \varepsilon_{1t} \quad (18)$$

This notation for causality lets one examine both short-run and long-run causal relationships. For instance, the short-run causality from X to Y is tested using a Wald test by executing $\alpha_{2i} = 0$. The long-run causality is examined according to statistical significance of the coefficient of the error correction term represented by ψ and Φ. For example, the statistically significant ψ indicates that X Granger causes Y in the long run.

5. Estimation results

Table 4 reports the results of ADF and PP unit root tests. According to Table 4, the series of lnSHALE (the natural logarithm of shale gas production) and lnIP (the natural logarithm of industrial production index) in the US do not follow stationary path in their levels but their first differences have tendency to converge to their means in the long run. In other words, the series are integrated of order 1, [$I(1)$]. In other words, a researcher may not be able to employ these variables in their levels in an econometric model unless they are cointegrated. If (a) they are integrated of order 1, [I(1)], and, (b) they are not found cointegrated, then, the estimation results would be inconsistent. Table 5 exhibits the outcome of Johansen [28,29] cointegration tests and yield the outcome that they are cointegrated. Johansen trace statistic reveals that the variables have at least one long run relationship. Hence, in terms of output of Tables 4 and 5, one may proceed to estimate the effect of lnSHALE on lnIP in an econometric analysis. However, ADF/PP unit root tests, and, Johansen cointegration test statistics do not employ inherently, in their testing procedure, the potential possible severe breaks that might have occurred in financial and/or industrial sectors. Therefore, to reach more reliable outcome, one might wish to observe the long run relationship analyses between shale gas and industrial production by taking into account possible structural breaks.

Then, one may need to launch, first, Carrion-i-Silvestre et al. [34] unit root test and, later, to conduct Maki [33] cointegration tests. Table 6 depicts the results of Carrion-i-Silvestre et al. [34] unit root test. Correspondingly, the test statistics for the first differences reject the null hypotheses and indicate that series are stationary in first differences. Namely, the series are found integrated of order 1, [$I(1)$].

The results of Maki [33] cointegration tests are denoted in Table 7. As a consequence, the cointegration tests indicate that the null hypothesis of no cointegration is rejected. Therefore, it can be claimed that there occurs a cointegration relationship between variables and that lnSHALE and lnIP converge to their long-run equilibrium by correcting any possible deviations from this equilibrium in the short run.

The breaking dates determined by Carrion-i-Silvestre et al. [34] unit root test and Maki [33] cointegration test correspond to some considerable periods for the US economy. Accordingly, the housing bubble-financial crises occurred in the US economy in 2007–2008 [102] may account for the breaks detected for 2008 in Tables 6 and 7 The financial crises due to the national debt-budget deficit and the second and third quantitative easing programs implemented by the FED [103,104] might be associated with the breaks in 2011 and 2012. One may indicate that (i) the London G20 summit decision to help IMF and to reform the banks, especially after Greek recession,

Table 4
ADF and PP unit root tests.

Variable[a]		ADF test statistic		PP test statistic	
		Intercept	Intercept and trend	Intercept	Intercept and trend
lnIP		−1.16	−4.48[b]	−1.20	−2.55
lnSHALE		−2.12	0.38	−2.01	0.37
ΔlnIP		−3.47[c]	−4.05[c]	−5.92[b]	−6.49[b]
ΔlnSHALE		−7.54[b]	−8.02[b]	−7.60[b]	−8.02[b]
Critical values	1%	−3.52	−4.09	−3.52	−4.09
	5%	−2.90	−3.47	−2.90	−3.47
	10%	−2.58	−3.16	−2.58	−3.16

Notes:
[a] Δ is the first difference operator.
[b] Illustrates 1% statistical significance.
[c] Illustrates 5% statistical significance.

Table 5
Johansen [28,29] cointegration test.[a,b]

Null hypothesis	Alternative hypothesis	Trace statistic	Critical value (1%)	Null hypothesis	Alternative hypothesis	Max-eigen statistic	Critical value (1%)
r = 0	r > 0	20.15[c]	19.93	r = 0	r = 1	15.07	18.52
r ≤ 1	r > 1	5.07	6.63	r = 1	r = 2	5.07	6.63

[a] All model selection criteria indicate 1 as the lag length. There are not serial correlation and heteroskedasticity problems for this lag length.
[b] r is the number of the cointegrating vector.
[c] Illustrates 1% statistical significance.

Table 6
Carrion-i-Silvestre et al. [34] unit root tests.[a]

Variable	P_T^{GLS}	MP_T^{GLS}	MZ_α^{GLS}	MSB^{GLS}	MZ_t^{GLS}	Break dates
lnIP	15.54 [9.32]	14.51 [9.32]	−30.88 [-47.42]	0.12 [0.10]	−3.92 [-4.84]	2008:7, 2009:2, 2010:4, 2011:1, 2012:7
lnSHALE	17.11 [9.05]	16.02 [9.05]	−26.75 [-46.54]	0.13 [0.10]	−3.62 [-4.79]	2008:12, 2009:9, 2010:6, 2011:1, 2011:12
ΔlnIP[b]	2.80[c] [5.54]	2.86[c] [5.54]	−32.04[c] [-17.32]	0.12[c] [0.16]	−3.99[c] [-2.89]	
ΔlnSHALE[b]	2.58[c] [5.54]	2.62[c] [5.54]	−34.93[c] [-17.32]	0.11[c] [0.16]	−4.17[c] [-2.89]	

Notes:
[a] Values in brackets are critical values obtained from bootstrap approach by Carrion-i-Silvestre et al. [51] at 0.05 level of significance.
[b] Δ is the first difference operator.
[c] Illustrates 5% statistical significance.

Table 7
Maki [33] cointegration tests.

Model	Test statistic	Critical values[a]			Break dates
		1%	5%	10%	
0	−4.83	−5.95	−5.42	−5.13	2008:12, 2009:5, 2010:4, 2010:12, 2011:4
1	−7.60[b]	−6.19	−5.70	−5.45	2008:5, 2008:12, 2009:5, 2011:5, 2012:10,
2	−7.70[b]	−6.91	−6.35	−6.05	2008:5, 2008:10, 2010:8, 2011:12, 2012:9
3	−8.47[b]	−8.00	−7.41	−7.11	2008:8, 2009:5, 2010:3, 2010:7, 2010:12

Notes:
[a] Critical values are obtained from Table 1 in Maki [33].
[b] Illustrates 1% statistical significance.

and, (ii) the first and second quantitative easing programs of the FED [104,105] might refer to fluctuations of 2009 and 2010 in the US.

Dummy variables of breaking periods obtained from Maki [33] cointegration test are included to the model to get long-term co-efficients. The long-term coefficients estimated through the DOLS approach are denoted in Table 8. As seen in the table, the coefficient of natural gas production from shale gas is positive and significant. Thereby, one may claim that natural gas production from shale gas has statistically significant and positive impact on industrial production.

Table 9 presents the results of Granger causality test based on vector error correction model. Accordingly, there is no causal relationship between variables in the short run while lnSHALE Granger causes lnIP in the long run. This finding concerning long-run relationship is consistent with DOLS results. When findings of the causality test are taken into account along with DOLS results, it can be easily argued that the growth hypothesis is valid between shale gas and industrial production in the US.

One may need to compare the findings of this paper with the outcome of current energy literature given in Tables 1 and 2 analyzing energy-growth nexus in general. Overall, one may claim that this paper employs cointegration analysis with structural breaks to explore possible long-term coefficient of natural gas production from shale gas on industrial production and obtains the growth hypothesis instead of the neutrality hypothesis. Therefore,

Table 8
Estimation of the long-term coefficients.[a]

Regressor	Coefficient	Standard error	p-value
lnSHALE	0.06[b]	0.01	0.00
d1	0.43[b]	0.12	0.00
d2	0.05	0.11	0.67
d3	−0.28[c]	0.11	0.02
d4	−0.04	0.11	0.70
d5	0.01	0.10	0.92
Intercept	3.67[b]	0.23	0.00
Adj. R^2 = 0.58, S.E. of regr. = 0.03, D-W stat. = 0.79.			

Dependent variable: lnIP.
Long-run variance estimate (Bartlett kernel, Newey-West fixed bandwidth = 4.00).
Notes:
[a] Break dates selected based on model 1 in Maki [33].
[b] Illustrates 1% statistical significance.
[c] Illustrates 5% statistical significance.

Table 9
Granger causality test based on vector error correction model.

	Short-run causality[a]		Long-run causality[b]
	ΔlnIP	ΔlnSHALE	ECT
ΔlnIP	–	0.10 (0.74)	−0.06[c] [-3.98]
ΔlnSHALE	1.35 (0.24)	–	0.01 [0.04]

Notes:
[a] The values in parentheses represent prob-values.
[b] The values in brackets denote t-statistics.
[c] Illustrates 1% statistical significance.

this paper may claim that the existing seminal studies on energy-GDP nexus may need to consider all relevant efficient and consistent cointegration equilibrium with structural breaks to reach efficient and unbiased long run coefficients of energy consumption on industrial production or GDP.

6. Conclusion

First we, authors, need to explore the originality of this work. The originality of this work lies in mainly two points. (1) The first immediate purpose of this work is to explore whether or not there exists indeed a ‘shale gas revolution’ in the US by investigating the available literature of shale gas in terms of its characteristics, challenges and prospects, (2) The second prompt purpose of this research is to measure, if exists, quantitatively the possible influence of shale gas revolution on the US economy through advanced time series estimation techniques. In other words, the main purpose of this research is, after considering an intensive literature review, to reach tangible quantitative measurement of co-movements between shale gas production and US industrial production.

One can follow directly the classical linear regression model (CLRM) to measure the effect of an independent variable (here, shale gas production) on dependent variable (here, industrial production) in general. Although CLRM seems to be a common approach to the literature of economics and/or energy, it might bear some undesirable statistical features. Because, first, CLRM does not consider, in general, the short run and long run effects' decomposition throughout estimations of impact of changes in independent variable on changes in dependent variable. Secondly, it does not keep track of the dynamics (leads and lags) which might exist inherently in relevant independent and dependent data. Thirdly, it does not take into account of possible potential structural breaks that might have been occurred in both dependent variable and dependent variable through estimated time horizon.

Due to potential statistical weaknesses of CLRM, we promote our work by launching some more advanced/desirable time series econometric models than the CLRM. These models are (i) Maki cointegration test, (ii) Dynamic Ordinary Least Squares (DOLS) estimator, and (iii) Granger causality test with vector error correction model (VECM), respectively.

Then, after conducting the relevant necessary unit root, cointegration and causality analyses of the estimated models in which possible structural breaks/regime shifts were observed, we might expose below the remarkable outcome of this research. In conclusion:

- This paper reviews the existing literature intensively and investigates the effects of natural gas production from shale gas on industrial production.
- After observing the structural breaks and long term coefficients, this paper yields that industrial production is positively related to natural gas production from shale gas.
- Therefore, this paper reveals, as well, that the growth hypothesis is valid between shale gas production and industrial production in the US.
- Eventually we conclude that the shale gas revolution of the US has significant positive effect on her GDP level. Considering this output, one may remark the relative importance of shale gas specifically as follows:
  a. Shale gas energy might decrease the energy dependence of the US,
  b. Shale gas might lower the prices of natural gas in the US,
  c. Shale gas may enhance employment and competitive power of the industrial sector of the US due to increasing shale gas production and low gas prices,
  d. Shale gas consumption, hence, might be expected to diminish CO_2 emissions of the US since shale gas is considered relatively clean-green source in comparison with fuel oil sources. For instance, a green energy of biomass consumption is found significant in lowering CO_2 emission in the US [44,106].

7. Policy implications

The results of the paper have important policy implications for other countries, as well, which have high shale reserves. According to EIA [26], top 5 countries with highest shale reserves are China, Argentina, Algeria, the US, and Canada, respectively (see Appendix). However, for the year 2012, the share of shale gas in natural gas production is 39%, 15%, and nearly 1% in the US, Canada, and China, respectively. This paper, then, claims that the shale revolution in the US will affect inevitably the energy policies of the countries with shale reserves. For instance, Hu and Xu [18] state that the shale revolution in the US draws attention of China and China has decided to utilize shale gas reserves to meet her huge energy demand. Thereby, the energy policies of other countries might be expected to consider prominently shale gas reserves in the near future.

This work is expected to initiate and/or accelerate ensuingly the further studies towards the effects of shale gas on energy demand, energy prices, and environment as well as on the welfare of societies.

Appendix. Top 10 countries with technically recoverable shale gas resource.

Rank	Country	Shale gas (trillion cubic feet)
1	China	1115
2	Argentina	802
3	Algeria	707
4	U·S.	665
5	Canada	573
6	Mexico	545
7	Australia	437
8	South Africa	390
9	Russia	285
10	Brazil	245
	WORLD TOTAL	7299

Source: EIA [48].

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