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RESEARCH ARTICLE

The shale gas production and economic growth in local economies across the US

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Abstract
Recently, several seminal works have been drawing attention to the revolution of shale gas production technology of the USA, the impact of shale gas on energy sectors, as well as the influences of shale gas on macroeconomic variables of employment, economic growth, etc. Nevertheless, one may claim that two gaps appear in literature. The first gap is the absence of an econometric study estimating the effect of shale oil/gas on national economies. The more considerable second gap is the absence of econometric analyses revealing the impulses of shale gas on local economies. Therefore, this paper observes the possible causalities between the shale gas and local gross domestic product (GDP) employing quarterly data covering the period 2007–2016 for 12 states in the US. After performing the tests of cross-sectional dependence, heterogeneity, stationarity, and cointegration, the paper conducts the panel Granger causality analyses. The empirical findings depict that (i) there is available unidirectional relationship from local shale gas production to local GDP in Colorado, Ohio, and West Virginia; (ii) there occurs an impulse from GDP to local shale gas production for Louisiana, North Dakota, and Oklahoma; (iii) a bidirectional causality coexists between local shale gas production and GDP in Arkansas, California, and Texas; and (iv) there exists no association between local GDP and local shale gas extraction in Montana, New Mexico, and Wyoming.

Keywords Shale gas · Energy-growth nexus · Cross-sectional dependence · Heterogeneity · The US economy · Local energy policies

Introduction

The technological methods developed through the combination of hydraulic fracturing and horizontal drilling in the early 2000s enabled the extraction of natural gas from shale formations (Gong 2018; Van der Ploeg and Rezai 2019). The natural gas production from shale formations in the US increased dramatically due to recent technological developments (Fleming et al. 2015). The US EIA data (2018) shows that, as there was not any contribution of shale to the total natural gas production in the 1990s, the share of shale gas raised in 2010 and 2014 by 20% and 44%, respectively. The US Department of Energy expects that this rise will continue in the following years (Taheripour and Tyner 2015) and estimates that natural gas production from shale reserves will increase by more than twice in the next 30 years (Munasib and Rickman 2015). Additionally, it is denoted that the shale formations can meet natural gas demand in the US in about 100 years (Wang et al. 2014). For this reason, the recent boom in shale gas and oil production might be considered the most recent important development in the energy sector that might lead to considerable developments in the global energy market (Wang and Li 2016; Balke et al. 2018; Tiwari et al. 2019). It is with no doubt that the boom in unconventional energy source of shale gas production has considerable effects in the US (Measham and Fleming 2014). The technological developments in the extraction method of shale gas caused a rise in companies dealing with gas extraction and improved the

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natural gas sector in the US (Ikonnikova et al. 2015). For instance, the Marcellus Shale in Pennsylvania is the largest natural gas field in the US, and led to 29,284 jobs, 238 million USD tax income, and 2.26 billion USD added value in 2008 (Considine et al. 2010). Besides, Hartley et al. (2015) denote that shale gas extraction has considerable positive effects on employment by generating 25,000–150,000 jobs in Texas.

When the other effects of shale gas extraction are considered, it is seen that the rise in shale gas extraction has caused natural gas unit prices to fall in the US (Brown Stephen 2017). The average (2000–2010) natural gas prices have fallen from \$6.81 to \$3.65 per mcf in 2011 (Hausman and Kellogg 2015). On the other hand, oil prices continue to increase (Wakamatsu and Aruga 2013). Therefore, the decline in prices of natural gas due to the shale revolution is the main advantage for the US (HIS-CERA 2012).

An increase in natural gas production with diminishing prices has stimulated production and employment in the US as expected. The shale industry has indirectly supported more than 600,000 jobs in the US, the US government obtained a considerable amount of tax incomes, and the low natural gas prices supported the chemical industry in the US in terms of the competitive power (Brown Stephen and Yücel 2013; Papatulica 2014; Wang et al. 2014). Along with low natural gas prices, shale gas production contributes to the energy safety and energy independence of the US. Before the shale gas extraction revolution, it was anticipated that the natural gas reserves of the US would drain away in 70 years (Brown 2014). With regard to EIA (2018) data, the US natural gas import increased from 3.7 trillion cubic feet (2000) to 4.6 trillion cubic feet (2007). Nevertheless, the prominent increase in shale oil and shale gas production caused the US natural gas import to decline to 2.7 trillion cubic feet in 2015, and thus reached the 1990s level. The shale production improved the trade balance of the US by reducing energy dependence of the US and so strengthened the US economy by contributing to energy safety (Medlock et al. 2011).

In the literature, it is also emphasized that shale gas production has considerable consequences on environmental policies in the US. Accordingly, coal is substituted with natural gas due to the boom in the production of shale gas and low natural gas prices (Brown Stephen et al. 2009; Brown and Krupnick 2010; Bazilian et al. 2014). As coal has far greater CO_2 emissions than natural gas has, CO_2 emissions in the US have decreased recently. De Gouw et al. (2014) point out that the expansion in the consumption of natural gas from power plants decreased CO_2 emissions by 23%, NO_x (nitrous oxide) by 40%, and SO_2 (sulfur dioxide) by 44% during the period 1995–2012 in the US. According to the IEA (2016) data, the CO_2 emissions from fossil-fuel reduced by 430 million tons for the period 2006–2011 in the US. It is no doubt that the production of shale gas has a considerable role in the reduction of CO_2 emissions in the US because natural gas is a much cleaner energy compared to coal.

Based on the explanations above, it is observed that the environmental and economic effects of the shale oil and gas revolution in the US draw attention to new challenges, opportunities, and discussions. However, the empirical researches towards the effects of this revolution might be considerably narrow. As Wang et al. (2014) stated, there has been an empirical evidence gap about the impacts of the shale extraction for the US. Therefore, this research aims at contributing to the literature of energy by focusing on the economic effects of the production of shale gas. Hence, the research investigates the causal association between GDP and shale gas production using quarterly data over the period 2007–2015 in the 12 states of the US.

This paper eventually has the purpose of adding new empirical evidence to the relevant energy literature by following five points.

First, even though there is intensive empirical evidence on the connection between energy production and/or consumption and economic growth (Ozturk 2010), the majority of empirical researches focuses on conventional energy sources rather than unconventional energy sources of shale gas. Therefore, this paper investigates the statistical correlation between unconventional energy and economic growth. Second, to the best of the authors' knowledge, this is the first research paper empirically examining the impact of shale gas production on GDP in the 12 states of the US using panel data techniques. Third, several panel data studies in the literature are criticized since they do not consider the cross-sectional heterogeneity issue within the panel (Bhattacharya et al. 2016). This paper considers not only heterogeneity but also the dependence among the cross-section units by performing recently developed panel data methods. Hence, this paper intends to reveal more consistent and reliable estimations. Fourth, when one searches the empirical evidence on energy-growth nexus in the US, he/she will observe that the papers focus on this nexus at a national level (see Table 1). However, this paper investigates this nexus at state levels. Fifth, one can observe from Table 1 that the papers exploring the energy-growth nexus yield mixed results. This paper also aims at revealing the reasons for the mixed results by considering nexus at the state level(s).

Following the "Introduction" section, the "Literature review" section of the paper exhibits the literature evidence. The "Data description and methods of estimation" section explains the data and methodology; estimation outputs are depicted in the "Findings" section; and finally, the "The practical facts underpinnings of the estimation output" section presents the main outputs, inferences, and policy suggestions.

Literature review

The relevant literature considers mainly the link between energy production/consumption and GDP within the frame of four well-known hypotheses. The first one is the growth

Table 1 Empirical evidence on the energy production/consumption-economic growth nexus in the USA

Author(s)	Period	Type of energy	Methodology	Conclusion
Kraft and Kraft (1978)	1947–1974	Conventional	Causality	Conservation
Akarca and Long (1980)	1950–1970	Conventional	Causality	Neutrality
Yu and Hwang (1984)	1947–1979	Conventional	Causality	Neutrality
Abosedra and Baghestani (1989)	1947–1987	Conventional	Causality and cointegration	Growth
Yu and Jin (1992)	1974–1990	Conventional	Causality and cointegration	Neutrality
Stern (1993)	1947–1990	Conventional	Causality	Growth
Cheng (1995)	1947–1990	Conventional	Causality and cointegration	Neutrality
Stern (2000)	1948–1994	Conventional	Causality and cointegration	Growth
Soytas et al. (2007)	1960–2004	Conventional	Causality	Neutrality
Sari et al. (2008)	2001:1–2005:6	Conventional	Causality and cointegration	Conservation
Payne (2009)	1949–2006	Conventional	Causality	Neutrality
Bowden and Payne (2009)	1949–2006	Conventional	Causality	Feedback (commercial and residential primary energy) Growth (industrial primary energy)
Bowden and Payne (2010)	1949–2006	Conventional	Causality	Feedback (non-renewable) Growth (renewable)
Payne and Taylor (2010)	1957–2006	Conventional	Causality	Neutrality
Payne (2011)	1949–2007	Conventional	Causality	Growth
Yildirim et al. (2012)	1949–2010 1960–2010 1970–2010	Conventional	Causality	Growth (biomass-waste-derived energy) Neutrality (total renewable energy consumption)
Aslan et al. (2014)	1973Q1-2012Q1	Conventional	Wavelet analysis and causality	Feedback
Bilgili (2015)	1981:1–2013:11	Conventional	Wavelet analysis	Growth
Aslan (2016)	1961–2011	Conventional	Causality and cointegration	Growth
Dogan and Turkekul (2016)	1960–2010	Conventional	Causality and cointegration	Conservation
Bilgili et al. (2017a)	1982–2011	Conventional	Causality	Growth
Nawaz et al. (2019)	1972–2017	Conventional	Causality and cointegration	Feedback
Tuna and Tuna (2019)	1980–2015	Conventional	Causality	Mixed results
Bilgili et al. (2016)	2008–2013	Unconventional (shale gas)	Causality and cointegration	Growth
Arora and Lieskovsky (2014)	1993:11–2012:12	Unconventional (shale gas)	Var-impulse-response	Growth

hypothesis indicating that there exists one-way causality running from energy production/consumption to GDP. Energy production/consumption has significant impacts on GDP as a supplementary of capital and labor. When this hypothesis prevails, the energy-saving policy affects economic growth adversely. Secondly, the feedback hypothesis assumes that a two-way relation is available between energy production/consumption and GDP. Accordingly, the positive or negative effects of energy shocks are transmitted to energy markets. The third hypothesis, called the conservation hypothesis, states that a unidirectional causality from GDP to energy production/consumption prevails. When this hypothesis is valid, energy-saving policies and energy shocks do not affect economic growth since economic growth promotes energy production/consumption. The fourth one is the neutrality hypothesis which assumes no association between income and energy usage. Increases in energy usage do not alter economic growth concerning this hypothesis.

There is an enormous and still extending literature on energy-growth nexus. Researches test the relationship between energy and economic growth by using different periods and methods for many developed and developing countries (Apergis and Payne 2011; Shahbaz and Lean 2012; Esso and Keho 2016; Koçak and Şarkgüneşi 2017; Erdoğan et al. 2019; Mele 2019; Ummalla and Samal 2018). An extensive literature survey is presented in the paper of Ozturk (2010). In this paper, we focus on the papers that examine the energy-growth nexus for the US. When these papers are examined, it is observed that the hypotheses explained above were tested throughout cointegration and causality analyses. Table 1 depicts the empirical evidence on the nexus between energy and economic growth for the US.

When one evaluates Table 1, he/she will observe four issues explained as follows:

1. All papers consider the link between energy and growth at the national level and there seems to be

no available paper examining the relationship at the state level(s).

2. These papers obtain mixed findings, and there is no agreement in the energy economics literature on this topic.
3. All papers, except Bilgili et al. (2016), investigate the impact of conventional energy sources (i.e., oil, conventional natural gas, coal, and renewables), on economic growth.
4. A new original research (this work) might contribute to the energy economics literature by considering the possible shock(s) of unconventional energy sources (shale oil and shale gas) on local/regional economies.

From this point of view, our paper aims at contributing to the energy economics literature by filling the research gap on the relationship between shale gas source and economic growth.

Data description and methods of estimation

Data description

The data consist of quarterly shale gas production (billion cubic feet) and GDP (billions of chained 2012 dollars) of 12 states in the US where shale gas has been extracted since 2007. The US states are Arkansas, California, Colorado, Louisiana, Montana, New Mexico, North Dakota, Ohio, Oklahoma, Texas, West Virginia, and Wyoming.[1] The main reason for the investigation of these 12 states is the availability of data. Shale gas is produced in 13 states of the USA. However, in the last few years, shale gas production has started in 3 more states. The quarterly data cover the period 2007:1–2016:4 and are obtained from EIA (2018) and the US Bureau of Economic Analysis (2018). The estimations are conducted by employing the logarithmic forms of shale (lnSHALE) and GDP (lnGDP).

Methods of estimation

The literature investigating causal relationships for panel data analyses might need to examine as well the probability of two considerable themes. The first theme is cross-sectional dependence in panel, indicating that a standard unit deviation in one cross-sectional unit can be transmitted to other units in the model. The second one is called slope heterogeneity that comes out when the slope coefficients are not the same in the model. It might be claimed that the hypothesis asserting that, within the panel, the variable X_i Granger causes the variable Y_i, for all i, as $i = 1, 2, \dots N$, is a powerful hypothesis (Granger 2003).

Then, observing the statistically possible availability of cross-unit dependence and slope heterogeneity is the first step in panel data analyses. Hence, the paper first analyzes the possibility of heterogeneity and cross-sectional dependence prior to unit root, cointegration, and causality tests.

Cross-sectional dependence and heterogeneity

The Lagrange multiplier (LM) tests are conducted by following Breusch and Pagan (1980) in order to detect, if exists, cross-sectional dependency. The following panel data model is estimated to reach the LM test output.

$$y_{it} = \alpha_i + \beta_i x_{it} + \varepsilon_{it} \; as \; i = 1, 2, \dots, N, \text{and } t = 1, 2, \dots, T \tag{1}$$

where i, t, and x_{it} denote the cross-section i, time t, and $nx1$ vector of regressors, respectively. The parameters of α_i and β_i stand for the constants and parameter coefficients, respectively. The LM test is computed as the following:

$$\mathrm{LM} = \mathrm{T}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^2 \sim \chi^2_{N(N-1)/2} \tag{2}$$

where $\hat{\rho}_{ij}$ stands for the pairwise correlation of the residuals acquired from the Eq. (1). The null hypothesis of no cross-sectional dependence is tested against the alternative hypothesis of cross-sectional dependence. Pesaran (2004) points out that this test may not be feasible if N is large. For large panels, Pesaran (2004) proposes the following type of the LM test:

$$\mathrm{CD}_{lm} = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(T\hat{\rho}_{ij}^2 - 1\right) \sim N(0,1) \tag{3}$$

This test may have considerable size distortions if T is small and N is large. Pesaran (2004) develops an alternative test, as is given in Eq. (4).

$$\mathrm{CD} = \sqrt{\left(\frac{2T}{N\left(N-1\right)}\right)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right) \sim N(0,1) \tag{4}$$

Pesaran et al. (2008) produce a bias adjusted type of the LM test for large panels as is defined in Eq. (5).

$$\mathrm{LM}_{adj} = \sqrt{\left(\frac{2}{N(N-1)}\right)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\frac{(T-k)\hat{\rho}_{ij}^2 - \mu_{Tij}}{\sqrt{\upsilon_{Tij}^2}} \sim N(0,1) \tag{5}$$

where k stands for the number of regressors, μ_{Tij} and υ_{Tij}^2 respectively signify the exact mean and variance of $(T-k)\hat{\rho}_{ij}^2$.

While examining slope heterogeneity, Pesaran and Yamagata (2008) develop delta $\left(\tilde{\Delta}\right)$ tests. The null hypothesis of slope homogeneity is investigated against the alternative hypothesis of slope heterogeneity. To generate $\tilde{\Delta}$ tests, first, the following modified type of the test of Swamy (1970) is computed:

$$\tilde{S} = \sum_{i=1}^{N}\left(\hat{\beta}_i - \tilde{\beta}_{WFE}\right)'\frac{X_i' M_\tau X_i}{\tilde{\sigma}_i^2}\left(\hat{\beta}_i - \tilde{\beta}_{WFE}\right) \tag{6}$$

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[1] We excluded Pennsylvania from the panel as shale gas has been produced in this state since 2008.

where

$$\widetilde{\sigma}_i^2 = \frac{\left(y_i - X_i\hat{\beta}_i\right)' M_\tau \left(y_i - X_i\hat{\beta}_i\right)}{(T-k-1)} \tag{7}$$

where M_τ is an identity matrix of order T and $\hat{\beta}_{WFE}$ is the weighted fixed effect pooled estimator described as follows:

$$\widetilde{\beta}_{WFE} = \left(\sum_{i=1}^{N} \frac{X_i' M_\tau X_i}{\widetilde{\sigma}_i^2}\right)^{-1} \sum_{i=1}^{N} \frac{X_i' M_\tau y_i}{\widetilde{\sigma}_i^2} \tag{8}$$

The standard dispersion statistic is given in Eq. (9).

$$\widetilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}\widetilde{S} - k}{\sqrt{2k}}\right) \tag{9}$$

With normally distributed errors, the small sample properties of the $\widetilde{\Delta}$ test can be enhanced by utilizing the mean and variance bias-adjusted type of $\widetilde{\Delta}$ as depicted by Eq. (10).

$$\widetilde{\Delta}_{adj} = \sqrt{N}\left(\frac{N^{-1}\widetilde{S} - E\left(\widetilde{z}_{iT}\right)}{\sqrt{Var\left(\widetilde{z}_{iT}\right)}}\right) \tag{10}$$

where

$$E\left(\widetilde{z}_{iT}\right) = k, \qquad Var\left(\widetilde{z}_{iT}\right) = \frac{2k(T-k-1)}{T+1} \tag{11}$$

The individual cross-sectionally augmented DF unit root test

Pesaran (2007) propounds unit root test for panel data models that can yield efficient output when there exist dependence and heterogeneity in cross-sections. He expands the augmented Dickey-Fuller (ADF) regressions via lagged levels' cross-section averages and the individual series' first differences. Hence, new tests' outputs are acquired through the individual cross-sectionally augmented DF (henceforth CADF) statistics and their averages as described in Eq. (12).

$$y_{it} = (1-\vartheta_i)\mu_i + \vartheta_i y_{i,t-1} + v_{it}, \text{as } i = 1, \ldots, N; \text{and as } t = 1, \ldots T \tag{12}$$

The residual term is defined as

$$v_{it} = \gamma_i f_t + \varepsilon_{it} \tag{13}$$

where f_{it} denotes the common effect which can observed, and ε_{it} stands for the unit-specific error.

Pesaran (2007) denotes that Eqs. (12–13) can be rewritten as follows:

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + \gamma_i f_t + \varepsilon_{it} \tag{14}$$

where $\alpha_i = (1-\Phi_i)\mu_i$, $\beta_i = -(1-\Phi_i)$ and $\Delta y_{it} = y_{it} - y_{i,\ t-1}$. The null hypothesis of non-stationarity (unit root) is denoted as the follows:

$$H_0 : \beta_i = 0 \text{ for all } i \tag{15}$$

The alternative hypothesis of stationarity is presented in Eq. (16):

$$H_1 : \beta_i < 0, i = 1, 2, \ldots, N_1, \beta_i = 0, \mathrm{i} = N_1 + 1, N_1 + 2, \ldots, N \tag{16}$$

Pesaran (2007) produces the stationarity test based on OLS t-ratio estimation of b_i $\left(\hat{b}_i\right)$ in the CADF as follows:

$$\Delta y_{it} = \alpha_i + b_i y_{i,t-1} + \sigma_i \overline{y}_{t-1} + \rho_i \Delta\overline{y}_t + e_{it} \tag{17}$$

The *t*-ratio, $t_i(N, T)$, is calculated as follows:

$$t_i(N, T) = \frac{\Delta y_i' \overline{M}_w y_{i,-1}}{\hat{\sigma}_i \left(y_{i,-1}' \overline{M}_w y_{i,-1}\right)^{1/2}} \tag{18}$$

For the whole panel, Pesaran (2007) computes the cross-sectionally augmented Im, Pesaran and Shin (CIPS) test statistic using the mean statistics of individual CADF test. CIPS statistic is demonstrated as follows:

$$CIPS(N, T) = t\text{-}bar = N^{-1}\sum_{i=1}^{N} t_i(N, T) \tag{19}$$

where $t_i(N, T)$ describes the CADF statistic for the ith cross-section unit.

Westerlund (2007) panel cointegration test

Westerlund (2007) suggests a test for the null hypothesis of no long-run relationship (cointegration) using the error correction model (ECM). He considers the data-generating process given in Eqs. (20) and (21).

$$y_{it} = \varphi_{1i} + \varphi_{2i}t + z_{it} \tag{20}$$

$$\partial_i(L)\Delta z_{it} = \partial_i\left(z_{it-1} - \beta_i' x_{it-1}\right) + \sigma_i(L)' z_{it} + e_{it} \tag{21}$$

where

$$\partial_i(L) = 1 - \sum_{j=1}^{p_i} \partial_{ij} L^j \text{ and } \sigma_i(L) = \sum_{j=0}^{p_i} \sigma_{ij} L^{j.}$$

By substituting Eq. (20) into Eq. (21), Westerlund (2007) obtains the following error correction model:

$$\partial_i(L)\Delta y_{it} = \varnothing_{1i} + \varnothing_{2i}t + \partial_i\left(y_{it-1} - \beta_i' x_{it-1}\right) + \sigma_i(L)' z_{it} + e_{it} \tag{22}$$

The ECM in Eq. (22) can be stable as $y_{it-1} - \beta_i' x_{it-1}$, z_{it}, and e_{it} are stationary. Besides, as $\partial_i = 0$, error correction term does not exist and {yit} is a unit root process which is not cointegrated with {xit}. If $\partial_i < 0$, the error correction term appears and implies the existence of cointegration between {yit} and {xit}.

To construct the test statistics, Eq. (22) is rewritten as

$$\Delta y_{it} = \varnothing_i' d_t + \partial_i \left(y_{it-1} - \beta_i' x_{it-1} \right) + \sum_{j=1}^{p_i} \partial_{ij} \Delta y_{it-j} + \sum_{j=0}^{p_i} \sigma_{ij} \Delta x_{it-j} + e_{it} \tag{23}$$

where $d_t = (1, t)'$ stands for the deterministic components and $\delta_i = (\delta_{1i}, \delta_{2i})'$ is the associated vector of parameters.

Equation (23) can be rewritten as is in Eq. (24).

$$\Delta y_{it} = \varnothing_i' d_t + \partial_i y_{it-1} + \delta_i' x_{it-1} + \sum_{j=1}^{p_i} \partial_{ij} \Delta y_{it-j} + \sum_{j=0}^{p_i} \sigma_{ij} \Delta x_{it-j} + e_{it} \tag{24}$$

Westerlund (2007) suggests four test statistics based on this equation. These test statistics are as follows:

$$G_\tau = \frac{1}{N} \sum_{i=1}^{N} \frac{\hat{\alpha}_i}{SE(\hat{\alpha}_i)} \tag{25}$$

$$G_\alpha = \frac{1}{N} \sum_{i=1}^{N} \frac{T\hat{\alpha}_i}{\hat{\alpha}_i(1)} \tag{26}$$

$$P_\tau = \frac{\hat{\alpha}}{SE(\hat{\alpha})} \tag{27}$$

$$P_\alpha = T\hat{\alpha} \tag{28}$$

Equations (25) and (26) reveal group mean statistics while Eqs. (27) and (28) exhibit panel statistics. For group mean statistics, H_0: $\alpha_i = 0$ for all i is tested against the H_1: $\alpha_i < 0$ for at least some i. The rejection of H_0 indicates the existence of cointegration for at least one cross-section. For panel statistics, H_0: $\alpha_i = 0$ for all i is tested against H_1: $\alpha_i = \alpha < 0$ for all *i*. The rejection of H_0 indicates the evidence of significant long-run equilibrium for the whole panel.

Panel causality test

Dumitrescu and Hurlin (2012) test the Granger non-causality considering the cross-sectional dependence and heterogeneity by estimating the parameters of Eqs. (29) and (30).

$$y_{i,t} = \gamma_i + \sum_{k=1}^{K} \rho_i^{(k)} y_{i,t-k} + \sum_{k=1}^{K} \varphi_i^{(k)} x_{i,t-k} + v_{i,t} \tag{29}$$

$$x_{i,t} = \lambda_i + \sum_{k=1}^{K} \varsigma_i^{(k)} x_{i,t-k} + \sum_{k=1}^{K} \zeta_i^{(k)} y_{i,t-k} + n_{i,t} \tag{30}$$

They assume that the individual effects γ_i and λ_i are fixed in the time dimension. Lag orders K are supposed to be the same for every cross-section unit in the panel. In addition, they allow the parameters $\rho_i^{(k)}$ and $\varsigma_i^{(k)}$ and the slopes $\varphi_i^{(k)}$ and $\zeta_i^{(k)}$ to vary among groups.

Dumitrescu and Hurlin (2012) conduct the estimations of Eq. (31) to test the homogeneous noncausality (HNC) hypothesis. One may observe, by following Eq. (31), the noncausality for some units under the alternative hypothesis as depicted in Eq. (32).

$$H_0 = \varphi_i = 0 \quad \Lambda i = 1, \ldots, N \tag{31}$$

with $\varphi_i = \left(\varphi_i^{(1)}, \ldots, \varphi_i^{(K)} \right)'$. By letting some $\varphi_i = 0$, under H_1, there are $N_1 < N$ individual processes with no causality from *x* to *y*.

$$H_1 : \varphi_i = 0 \quad \Lambda i = 1, \ldots, N_1 \tag{32}$$

$$\varphi_i \neq 0 \quad \Lambda i = N_1 + 1, N_1 + 2, \ldots, N$$

where N_1 is unknown and satisfies the condition $0 \leq N_1/N < 1$. If one rejects H_0 of (31) with $N_1 > 0$, then, he/she can reach the output that variable *X* can forecast variable *Y* for some units in the panel.

Findings

Table 2 shows the existence of significant cross-sectional dependence at 1% level indicating that a shock that occurs in one of state in the US can influence other states in the US. Additionally, Table 2 output confirms slope heterogeneity and, hence, support the existence of state-specific heterogeneity.

Table 3 presents the findings of the CADF panel unit root test. According to the findings, lnGDP is stationary for Arkansas and Texas while lnSHALE is stationary for Texas. Besides, ΔlnGDP is stationary at all states except Louisiana while ΔlnSHALE is stationary at all states except Montana and West Virginia. CIPS statistics concur with individual findings and indicate both variables are stationary at first differences for the whole panel. Therefore, one can determine that both variables are stationary at first differences. Based on evidence of the CADF unit root test, one also needs to employ next the cointegration tests, developed by Westerlund (2007), to examine the probability of cointegration relationship between variables.

Table 4 reports the results of the Westerlund (2007) cointegration test. As is seen from the table, the null hypothesis of no cointegration can be rejected by two out of four statistics. Then, one can decide that there exists probably a cointegration relationship between lnGDP and lnSHALE by G_τ and P_τ statistics at 1% and 5% significances. The causal relationships between variables, next, can be detected through the causality test propounded by Dumitrescu and Hurlin (2012).

Table 5 presents the outcome of the Dumitrescu and Hurlin (2012) panel causality test. As is seen, both the null hypothesis

Table 2 The output from the tests for slope heterogeneity and cross-sectional dependence

	Statistic	Prob-value
Cross-sectional dependence		
LM	405.780[a]	0.00
CD_{LM}	29.574[a]	0.00
CD	6.037[a]	0.00
LM_{adj}	113.062[a]	0.00
Heterogeneity		
$\tilde{\Delta}$	24,640.718[a]	0.00
$\tilde{\Delta}_{adj}$	25,938.475[a]	0.00

[a] One percent statistical significance

of no causality from lnSHALE to lnGDP and no causality from lnGDP to lnSHALE can be rejected by the statistics of six out of the twelve states. Accordingly, there is a causal relationship running from lnSHALE to lnGDP in Arkansas, California, Colorado, Ohio, Texas, and West Virginia while there is a causal relationship running from lnGDP to lnSHALE in Arkansas, California, Louisiana, North Dakota, Oklahoma, and Texas.

This paper is mainly interested in the nexus between energy production/consumption and GDP through four hypotheses. These hypotheses are, as explained in the "Literature review" section, growth, feedback, conservation, and neutrality, respectively. When one evaluates the findings with regard to four hypotheses, he/she will observe the statistical evidence in favor of all hypotheses.

Table 3 Individual cross-sectionally augmented DF panel unit root tests[a]

State	Test statistic			
	lnGDP	ΔlnGDP	lnSHALE	ΔlnSHALE
Arkansas	−3.182[d]	−5.072[b]	−2.832	−3.129[d]
California	−0.883	−3.363[c]	−1.964	−3.979[c]
Colorado	−0.774	−3.624[c]	−1.638	−4.456[b]
Louisiana	−2.592	−2.553	−1.671	−3.313[d]
Montana	−1.160	−4.805[b]	−1.618	−2.794
New Mexico	−0.671	−3.896[c]	−1.102	−5.150[b]
North Dakota	−0.222	−3.166[d]	−2.572	−4.257[b]
Ohio	−2.445	−3.257[d]	−2.163	−3.690[c]
Oklahoma	−1.765	−3.635[c]	−2.556	−4.271[b]
Texas	−2.978[d]	−3.700[c]	−3.197[d]	−3.737[c]
West Virginia	−2.401	−3.647[c]	−2.497	−2.788
Wyoming	−1.842	−3.873[c]	−2.642	−3.488[c]
Panel (CIPS)	−1.743	−3.716[b]	−2.204	−3.754[b]

[a] Critical values for states' statistics corresponding to 1%, 5% and 10% significance levels are −4.11, −3.36, and −2.97, respectively. The critical values for whole panel statistics corresponding to 1%, 5%, and 10% significance levels are −2.57, −2.33, and −2.21, respectively (Pesaran 2007)

[b] One percent statistical significance

[c] Five percent statistical significance

[d] Ten percent statistical significance

Table 4 Cointegration test by Westerlund (2007)

Statistic	Value	p value
G_τ[a]	−4.973[a]	0.000
G_α	−4.228	0.971
P_τ[b]	−6.881[b]	0.040
P_α	−3.267	0.794

[a] One percent statistical significance

[b] Five percent statistical significance

Table 6, following Table 5, explores the output of hypothesis tests across states. Accordingly, the growth hypothesis prevails for Colorado, Ohio, and West Virginia while the feedback hypothesis is valid for Arkansas, California, and Texas. In addition, the conservation hypothesis appears in Louisiana, North Dakota, and Oklahoma while the neutrality hypothesis dominates Montana, New Mexico, and Wyoming.

The practical facts underpinnings of the estimation output

In order for the potential reader to be able to follow clearly the output of this research regarding 12 states' energy potential and their gross domestic products, this section will reveal more theoretical and practical features of the states with high shale reserve in terms of nexus between their shale energy and income growth. Therefore this section will explore theoretical extensions and practical underpinnings of the estimation output of Arkansas, California, Colorado, Louisiana, Montano, New Mexico, North Dakota, Ohio, Oklahoma, Texas, West Virginia, and Wyoming. Figure 1 exhibits the geographical locations of 12 US states with greater shale gas deposits among other US states. One may observe that states with considerably high shale plays seem to cluster mostly in the North and South regions of the US. Shale reserves are also considered significant in California (West) and Ohio and West Virginia (East).

The researches, in general, show that, in the US, employment and income from shale gas plays have increased. The Bureau of Economic Analyses and US Census Bureau statistics indicate that the employment grew more in counties with shale boom than the counties without shale boom (Weber 2012). Figure 2 reveals that, in the US, the employment and income levels in counties have advanced considerably through the shale gas revolution. For instance, based on data for Colorado, Texas, Wyoming, and Pennsylvania and other

Table 5 Panel causality test by Dumitrescu and Hurlin (2012)

State	H_0: lnSHALE does not cause lnGG$_{\tau}$DP		H_0: lnGDP does not cause lnSHALE	
	Wald statistic	Result[d]	Wald statistic	Result[e]
Arkansas	9.950[b]	Causality	43.714[a]	Causality
California	7.886[c]	Causality	10.774[b]	Causality
Colorado	9.260[c]	Causality	7.212	No causality
Louisiana	2.601	No causality	10.284[b]	Causality
Montana	0.192	No causality	6.981	No causality
New Mexico	5.358	No causality	4.103	No causality
North Dakota	5.749	No causality	25.082[a]	Causality
Ohio	16.600[a]	Causality	3.531	No causality
Oklahoma	4.656	No causality	104.445[a]	Causality
Texas	13.640[a]	Causality	17.485[a]	Causality
West Virginia	9.048[c]	Causality	2.295	No causality
Wyoming	3.001	No causality	4.654	No causality

[a] One percent statistical significance

[b] Five percent statistical significance

[c] Ten percent statistical significance

[d] "Causality" stands for the significant impact of shale gas production (lnSHALE) on income (lnGDP), while "no causality" implies the insignificant effect of shale gas on income

[e] "Causality" indicates significant impact of income on shale gas production, whereas "no causality" points out the insignificant influence of income on shale gas production

relevant states, statistics yield that, from 1999 to 2007, the annual percentage increases of employment levels in boom counties and not boom counties are 2.4 and 1.6, respectively (Weber 2012). The annual labor income percentage increases in boom and not boom counties appear to be 4.4 and 2.5, respectively, for the period 1999–2007 (Weber 2012).

Jacoby et al. (2012) emphasize the relatively greater shale gas deposits, among other states, in Barnett, Haynesville, Fayetteville and Woodford shale productions in Texas, Louisiana, Arkansas, and Oklahoma. Jacoby et al. (2012) and Evensen and Stedman (2016) underline the prominent shale reserves in Marcellus which refer to geological formation underlining the parts of New York, Pennsylvania, Ohio, and West Virginia.

Table 6 The output of hypotheses' tests across the states

States	Validated hypothesis			
Arkansas		Feedback		
California		Feedback		
Colorado	Growth			
Louisiana			Conservation	
Montana				Neutrality
New Mexico				Neutrality
North Dakota			Conservation	
Ohio	Growth			
Oklahoma			Conservation	
Texas		Feedback		
West Virginia	Growth			
Wyoming				Neutrality

Table 5 exhibits that shale gas production has significant development on income levels of Arkansas, California, Colorado, Ohio, Texas, and West Virginia. Considering Table 5, one might also need to observe specifically the response of macrovariables, i.e., employment, GDP growth, price level, and/or energy prices, to the impulse of shale gas revolution in Arkansas, California, Colorado, Ohio, Texas, and West Virginia.

The contribution of freight truck, crude petroleum and natural gas extraction, and natural gas distribution to the Arkansas economy was $5.27 billion in 2015 (API 2017b) due to the shale gas revolution. Nyquist and Lund (2014) point the fact that more than 100 billion worth of foreign direct investment intends to be part of the shale gas boom in Ohio, Louisiana, and Arkansas. Munasib and Rickman (2014) investigate the effectiveness of the shale gas revolution on the local economies in the counties of Arkansas, North Dakota, and Pennsylvania. They explore that the sharp increase in shale gas caused significant strengths in employment in four counties in Arkansas. Weber (2012),Weber 2013) observes the power of natural gas development on counties in Colorado, Texas, and Wyoming and reveals that, for the period 1999–

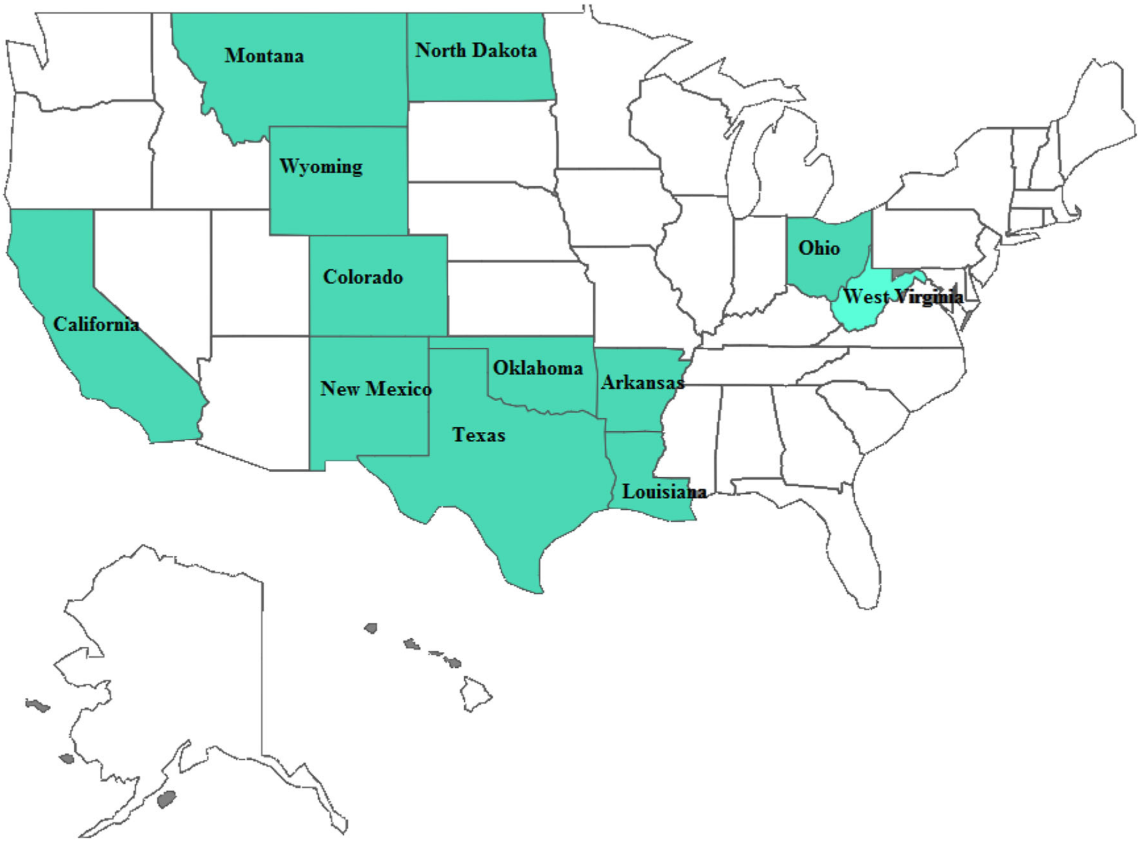

Fig. 1 12 states with greater shale gas deposits

2007, gas industry produced additional 1780 jobs which approximated 27 jobs per every billion cubic feet of production to the average county experiencing a boom.

Geng et al. (2016) state that the North American oil and natural gas prices have been diverged since the shale gas revolution. They found that, after, shale gas revolution, the natural gas prices in North America changed from "slightly upward" to "sharply downward." Mathieu et al. (2014) explore that the increase in domestic energy production through US shale gas energy boom decreased imports of oil and gas into the US, and, hence lowered energy prices in the country. These advantages eventually provided policymakers with possible strict policies and regulations on coal-fired power plants. Mathieu et al. (2014), on the other hand, argue that the long-run positive impacts of the shale gas boom on the US economy might be relatively small. Weber (2013) anticipates that the different potential responses of counties to the shale boom as shale gas production has been slowing down. He

Fig. 2 Employment and income in counties with shale gas revolution: 1999–2007. Source: Weber (2012)

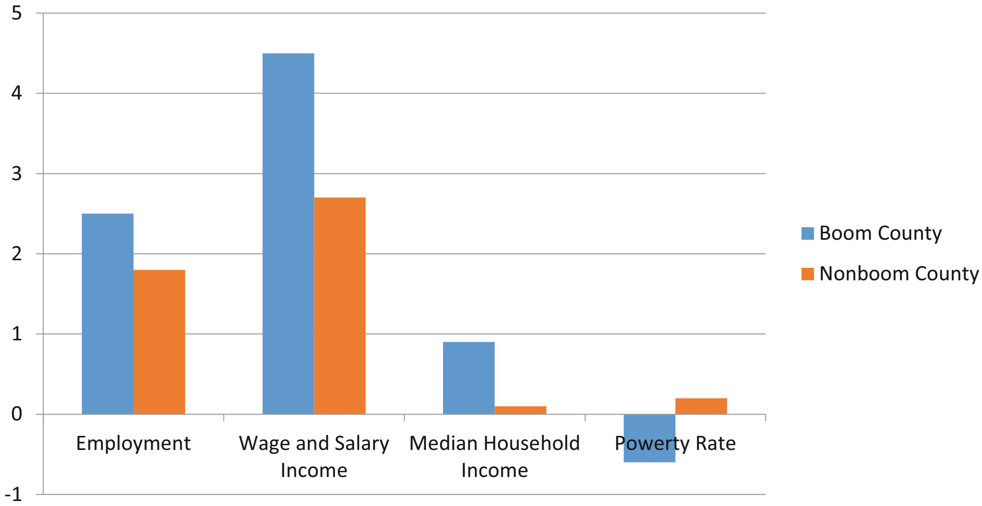

Table 7 Shale gas related jobs and income across states

States	
Arkansas	The forecasted labor income contributions of the non-conventional (shale) gas industry correspond to $2314 million and $3407 million in 2010 and 2015, respectively (Bonakdarpour and Larson 2012). In terms of 2015, the natural gas market provided the state with 40,546 jobs which depict 3.4% of total Arkansas jobs. The market contributed $5.27 billion income in Arkansas (API 2017b).
California	The predicted the number of jobs due to oil and shale gas industries by two scenarios (low and medium scenarios) ranges from 67,175 to 299,242 in 2011. The net benefit for the economy from oil and shale gas markets is anticipated to be in range of $7093 billion to $30,860 billion (Considine 2014). The anticipated labor income of shale gas in terms of 2010 and 2015 are $1553 million and $2295 million, respectively (Bonakdarpour and Larson 2012).
Colorado	The forecasted labor income of non-conventional (shale) gas industry corresponds to $5958 million and $9258 million in 2010 and 2015, respectively (Bonakdarpour and Larson 2012). Natural Gas industry in Colorado resulted in 75,210 jobs representing 3% of the total jobs and created $10.4 billion in the state (API 2017c).
Louisiana	The forecast values for labor income contributions of non-conventional (shale) gas industry correspond to $5492 million and $9238 million in 2010 and 2015, respectively (Bonakdarpour and Larson 2012). In terms of 2015, the natural gas sector created 201,319 jobs representing 10.5% of total jobs in Louisiana and contributed the value of $28.6 billion in the state. The horizontal play of Haynesville was expanded through 38 onshore and 20 offshore activities in 2017 (API 2017d).
Montana and North Dakota	Horizontal drilling and hydraulic fracturing techniques in oil-producing shale formation of North Dakota and Montana (The Bakken Formation) have brought about sharp increases in oil extraction from shale formations. Employment in these states increased from 77,937 jobs in 2007 to 105,891 jobs in 2011 (Ferree and Smith 2011). In counties of Montana and North Dakota, total wage payments for workers grew from $2.6 billion in 2007 to $5.4 billion in 2011 (Ferree and Smith 2011). 11,500 jobs were available in the natural gas related industry of Montano standing for 2.6% of total jobs in the state in 2015. The contribution of natural gas industry to the state $1.48 billion in 2015 (API 2017e). The number of jobs and income created by natural gas industry in North Dakota were 32,300 jobs, corresponding to 7.5% of total state jobs, and $3.84 billion, respectively, in 2015 (API 2017f).
New Mexico	The oil and natural gas industry yields 15,093 jobs and 18,560 jobs in 2007 and 2012, respectively (JPP 2017). The available jobs in the industry jumped to 39,925 in 2015 (API 2017g). The forecast values of labor income of non-conventional (shale) gas industry are $1461 million and $1407 million in 2010 and 2015, respectively (Bonakdarpour and Larson 2012).
Ohio	The forecast values of labor income at non-conventional (shale) gas industry are $2031 million and $2684 million in 2010 and 2015, respectively (Bonakdarpour and Larson 2012). The natural gas market provided Ohio with 188,500 jobs, which was equal to 3.6% of the total jobs, and $26.7 billion income in 2015 (API, 2017 g).
Oklahoma	Oil and natural gas industry supports 44,005, 56,040, and 117,700 jobs in 2007, 2012 (Cruz et al. 2014), and in 2015 (API 2017i), respectively. Anticipated state level income from shale gas in 2010 and 2015 are $1993 million and $2961 million, respectively (Bonakdarpour and Larson 2012).
Texas	The oil and natural gas industry leads to 194,898 jobs and 259, 333 jobs in 2007 and 2012, respectively (Cruz et al. 2014). The number of jobs increased to 784, 900 in 2015 (API 2017j). The forecasted labor income of non-conventional (shale) gas industry in 2010 and 2015 are $22,840 million and $30,769 million, respectively (Bonakdarpour and Larson 2012).
West Virginia	The employment share of oil and natural gas industry among other industries increased slowly from %2 in 2000 to approximately %5 in 2011 (Brown and Yucel 2013). The anticipated labor income of non-conventional (shale) gas industry in 2010 and 2015 are $1091 million and $2088 million, respectively (Bonakdarpour and Larson 2012). The estimated number of jobs due to Marcellus shales activities in West Virginia and Pennsylvania were 57,357 in 2009, 118,078 in 2011 and 158,408 in 2015 under medium development projection (Considine 2010). The realized number of jobs in West Virginia was 35,800 in West Virginia in terms of 2015 (API 2017k).
Wyoming	The oil and natural gas industry supports 17,743 jobs and 17,121 jobs in 2007 and 2012, respectively (Cruz et al. 2014). The number of jobs jumped to 29,500 in Wyoming in 2015 (API 2017l). The forecasted labor income of non-conventional (shale) gas industry are $2753 million and $3669 million in 2010 and 2015, respectively (Bonakdarpour and Larson 2012).

emphasizes the effect of shale drilling on local economies of rural, more rural and less populated areas. He exhibits, i.e., that in rural areas, businesses formed solely to service the industry might fade as quickly as they came.

Table 7 exposes specifically the shale gas-related jobs and income across 12 states. Table 7 indicates that, for instance, the number of jobs in the states due to the natural gas industry increased prominently. For instance, in Wyoming, the oil and natural gas industry provided the state with 17,743 jobs and 17,121 jobs in 2007 and 2012, respectively (Cruz et al. 2014). The number of jobs became 29,500 in Wyoming in 2015 (API 2017a). In New Mexico, the employment level increased from 18,560 jobs in 2012 (JPP 2017) to 39,925 jobs in 2015 (API 2017a).

Table 7, for example, explores as well that in Oklahoma the number of jobs due to oil and natural gas industry jumped from 56,040 jobs in 2012 (Cruz et al. 2014) to 117,700 jobs in 2015 (API 2017a). As given in the table, the projections reveal that labor income levels from shale industries in Arkansas, California, Louisiana, New Mexico, Ohio, Oklahoma, Texas,

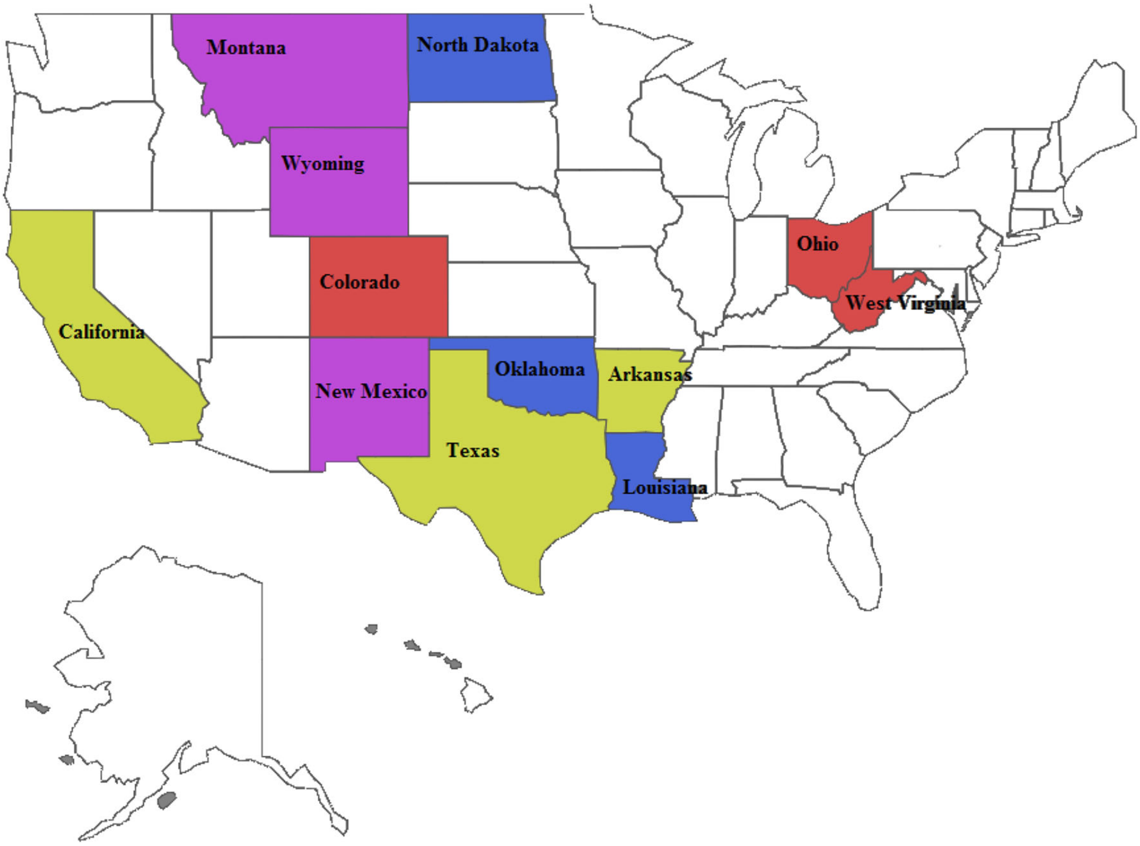

Fig. 3 The output of hypotheses' tests across 12 states: 2007:1–2016:4. Colorado, Ohio, and West Virginia confirm growth hypothesis. California, Texas, and Arkansas verify feedback hypothesis. North Dakota, Oklahoma, and Louisiana support conservation hypothesis. Montano, Wyoming, and New Mexico confirm the neutrality hypothesis

West Virginia, and Wyoming in 2010 are \$3407 million, \$1553 million, \$5492 million, \$1461 million, \$2031 million, \$1993 million, \$22,840 million, \$1091 million, and \$2753 million, respectively (Bonakdarpour and Larson 2012).

The percentage increases in forecast values of labor income of shale plays, i.e., in California, Colorado, Louisiana, Texas, and Wyoming, from 2010 to 2015, are 0.478, 0.534, 0.682, 0.347, and 0.332, respectively.

Figure 3, following Tables 5 and 6, depicts the output of hypotheses' tests across 12 states. It yields that Colorado, Ohio, and West Virginia follow the growth hypothesis. The growth hypothesis prevails when there is unidirectional causality from energy consumption to economic growth. According to this hypothesis, energy serves as a supplementary of labor and capital and is a vital component of economic growth (Apergis and Payne 2009). All production processes include a transformation. Energy is needed for this transformation and energy cannot be substituted with any other inputs (Stern 2004). Hence, the growth hypothesis asserts that production depends on energy. Energy-saving policies, energy scarcity, and energy supply shocks negatively affect economic growth and employment (Jumbe 2004).

The implications of this hypothesis are especially important for policies that aim at reducing CO_2 emissions since these policies restrict energy consumption. However, as denoted above, energy-saving policies might have negative impacts on economic growth and employment. Therefore, for sustainable development, policymakers should design energy supply and demand policies considering past growth rates and future growth targets. Besides, in order to decrease CO_2 emissions, instead of restricting energy consumption, policymakers should try to substitute conventional energy sources with unconventional and renewable energy sources and to develop new technologies using energy sources more productively.

Considering Tables 5 and 6 and Fig. 3, one can observe that the conservation hypothesis is held in Louisiana, North Dakota and Oklahoma. When there exists a unidirectional causal relationship running from economic growth to energy consumption, the conservation hypothesis is valid. As Parikh and Shukla (1995) and Madlener and Sunak (2011) remark, according to this hypothesis, economic growth contributes to manufacturing, transportation, and urbanization and accelerates infrastructure and consumption expenditures. Hence, all these effects increase energy demand. Additionally, economic growth ultimately promotes more energy consumption even though it increases energy productivity by supporting the development of large-scale energy technologies (To et al. 2013). Since there is unidirectional causality from economic growth to energy consumption by this hypothesis, energy-saving policies aiming to reduce CO_2 emissions and energy supply shocks do not have significant effects on economic growth.

The states of Montano, New Mexico, and Wyoming follow the neutrality hypothesis. The neutrality hypothesis dominates if there is no causality between economic growth and energy consumption. This hypothesis indicates that an increase or a decrease in energy consumption does not affect economic growth and employment. Some papers in the literature assert that this hypothesis can prevail when (i) the ratio of energy costs to GDP is low and (ii) the effect of energy consumption on economic growth can differ by the structures of economies, institutional factors, and the levels of development of countries (Yu and Choi 1985; Apergis and Payne 2009, Belloumi 2009; Payne 2010; Too et al. 2013). This hypothesis may especially prevail for some economies whose production structures shift from the industry sector to information and service sectors that do not use energy intensively. Hence, this hypothesis denotes that energy supply shocks and energy-saving policies aiming to reduce CO_2 emissions do not have significant effects on economic growth.

Finally, according to the output of this paper, the feedback hypothesis is held in Arkansas, California, and Texas. As there happens to be bidirectional causality between economic growth and energy consumption, the feedback hypothesis prevails. This hypothesis implies that economic growth and energy consumption support each other and are jointly determined. Accordingly, energy is a basic element of economic processes, and production activities rely on energy. Besides, this relationship is not unidirectional and economic growth encourages energy consumption. For this reason, this hypothesis indicates that policymakers should consider this interaction while they are designing energy policies. Policymakers should also develop policies that use energy more efficiently and should promote the usage of more clean and non-polluting energy sources with regard to this hypothesis.

Discussion, conclusion, and policy implications

Discussion and conclusion

The prominent developments in oil and gas production from shale formations brought about new investment and employment opportunities in the national level and local level economies. The existing literature has recently focused on the impact of shale gas on country level macroeconomic indicators as there has been very limited observations on the influences of shale gas production on local economies (Munasib and Rickman 2015; Cooper et al. 2018; Whyman 2015). Whyman (2015), for instance, reviews and compares well the economic implications of shale gas reserves in the US and UK through some input-output model estimations. To this end, this work mainly focuses on the effect of recent developments in shale extraction technologies yielding an unconventional oil production on the state level economies in the US through recent advanced time series and panel data estimations.

This paper's output provides the policymakers with a guide service in which they can observe heterogeneous impacts of shale gas extraction on the states. The impact of unconventional oil production from shale gas formation is subject to change from a state to another state in the US depending on prevailing local level infrastructure, alternative energy sources, and market size.

The paper examines the causal relationships between shale gas production and GDP by utilizing quarterly data from 2007:1–2016:4 for 12 states in the US. After conducting cross-sectional dependence, heterogeneity, unit root, and cointegration tests, the paper performs the panel Granger causality test developed by Dumitrescu and Hurlin (2012).

This paper may reveal its basic findings and its policy recommendation as follows:

(a) Colorado, Ohio, and West Virginia confirm growth hypothesis; California, Texas, and Arkansas verify feedback hypothesis. North Dakota, Oklahoma, and Louisiana support conservation hypothesis. Montano, Wyoming, and New Mexico confirm the neutrality hypothesis.

(b) According to the findings, (i) there is unidirectional causality running from shale gas production to GDP, and thus, the growth hypothesis is valid in Colorado, Ohio, and West Virginia; (ii) there is bidirectional causality between shale gas production and GDP, and thus, the feedback hypothesis prevails in Arkansas, California, and Texas; (iii) there is unidirectional causality running from GDP to shale gas production, and thus, the conservation hypothesis prevails in Louisiana, North Dakota, and Oklahoma; and (iv) there are no causal relationships between shale gas production and GDP, and thus, the neutrality hypothesis dominates in Montano, New Mexico, and Wyoming.

The analyses have reached empirical evidence indicating that (i) energy consumption and economic growth have positive co-movements (positive associations) in Arkansas, California, and Texas; (ii) there exists no significant causality from energy consumption to growth in Montano, New Mexico, and Wyoming. Therefore, upon this conclusion, authorities might follow some energy supply-side or energy demand-side policies to expand the market size, employment and job opportunities in Arkansas, California, and Texas rather than Montano, New Mexico, and Wyoming. This research suggests as well that authorities follow expansionary energy demand policies to boost the local level employment level and income level in Colorado, Ohio, and West Virginia.

Policy implications

Policy recommendation for Colorado, Ohio, and West Virginia in which growth hypothesis is confirmed: Under this hypothesis, natural gas production from shale wells has positive significant impacts on gross domestic products as supplementary of capital and labor. Authorities first need, as always, to determine the states' priorities. If the societies of Colorado, Ohio, and West Virginia prefer primarily to have significantly growing local economies, they will need to follow the policies to increase the production and consumption of shale gas energy due to significant positive influence of shale gas on local income levels. In this policy framework following the growth hypothesis, hence, authorities are expected to launch additional subsidies, tax incentives, and supportive infrastructures to intensify the shale gas exploration within their local areas. This will, in turn, boost the employment levels of labor and capital, and eventually the gross domestic income levels in Colorado, Ohio, and West Virginia. The potential energy-saving policies, on the other hand, will have prominently negative effects on the gross domestic incomes of the relevant states.

Policy recommendation for North Dakota, Oklahoma, and Louisiana in which conservation hypothesis is supported: Under this hypothesis, natural gas production from shale fields will not affect the economic growth but economic growth will induce shale usage. Administrators might consider following the relevant policies to save especially fossil fuel energy, and/or, to switch energy consumption patterns from fossil fuel to clean energy. Energy-saving targets and the target for changing energy preferences of the societies will create eventually some shocks in energy markets. The shocks (impulses) in the markets, however, will not enlarge the time-frequency periods of business cycles (responses) of the states of North Dakota, Oklahoma, and Louisiana, and hence will not affect gross domestic levels of the states. Under the conservation hypothesis framework, the policymakers of North Dakota, Oklahoma, and Louisiana will have more room to be able to overwhelm the environmental degradation due to high CO_2 emissions from fuel combustion in comparison with, for instance, the policymakers of Colorado, Ohio, and West Virginia.

Policy recommendation for California, Texas, and Arkansas in which feedback hypothesis is verified. Under the evidence of confirming this hypothesis, the additional volume of shale gas exploration will expand the gross domestic income of the sates, and expansion of income levels of the states will accelerate the shale gas production in the states. The shale gas consumption and states' GDPs have mutual positive responses to each other's impulses (shocks) in California, Texas, and Arkansas. When this hypothesis prevails, two possible outcomes might emerge: (a) the shale energy-saving policy will affect the economic growth adversely, and (b) any contractionary fiscal or monetary policy will have the potential to lower the shale energy extraction. As in the case of Colorado, Ohio, and West Virginia following growth hypothesis, the policymakers of California, Texas, and Arkansas might be suggested that they implement stimulative actions on electricity generation from shale gas fields. Such actions under this hypothesis will be expected to bring about greater multiplier effects of shale consumption on GDP in comparison with the effects of the same actions undergrowth hypothesis. This latter statement seems to be true, at least hypothetically, due to the mutual interaction of shale gas usage and GDP in California, Texas, and Arkansas. The potential advantage of these local economies verifying feedback hypothesis against other states' local economies might be a more plausible contribution to the fighting against local/national/global warming.

Policy recommendation for Montano, Wyoming, and New Mexico supporting neutrality hypothesis. Within the frame of the neutrality hypothesis, neither shale gas consumption level nor the level of GDPs' of the sates can alter each other. The policy administrators can consider implementing independent energy policies without affecting the local income levels. As in the case of North Dakota, Oklahoma, and Louisiana, the authorities might conduct energy-saving policies to combat environmental degradation without harming economic growth.

The result of this paper considers also possible environmental policies as well as economic policies. Then, the paper might suggest that the policymakers might follow successfully the energy-saving policies which aim at diminishing CO_2 emissions, without any adverse effect on employment level, in Louisiana, North Dakota, and Oklahoma rather than the states of Colorado, Ohio, and West Virginia in which energy-saving policies might reduce the employment and hence economic development. The policymakers, on the other hand, might substitute conventional energy sources with unconventional and renewable energy sources and develop new technologies using energy sources more productively in order to reduce the environmental pollutant level.

Therefore, instead of implementing general/standard national-level energy policies at local economies, the administrators need to consider greatly the advanced statistical analyses estimating the output of "Growth," "Feedback," "Conservation," and "Neutrality" hypotheses to be able implement local specific energy policies which can optimize the benefits from shale gas production at local areas in terms of environmental quality and economic growth.

The sustainable growth, targeting both green environment and income growth simultaneously, has been the main goal of the United Nations, IEA, and World Bank. At the beginning of 2010s, the head of IEA addresses the target for increasing the share of renewables of the countries without adverse effects on the economies (Boehmer-Christiansen 2011, 2013). However, the energy policy changes of IEA in the beginning of 2010s which aim at supporting the renewables, instead of fossils, to cope with adverse effects of climate change without harming the economic growth will be successful if targeted countries have the similar evidence of validating either conservation hypothesis, or feedback hypothesis or neutrality hypothesis. Reducing negative effects of climate change might be successful, on the other hand, together with (i) the policy of efficient usage of renewables, i.e., efficient production and consumption of solar, as indicated in Cardenas et al. (2017), and (ii) the policy to lower energy intensity in local and national levels as underlined in Dong et al. (2018). One might reach also the outcome of nexus between energy intensity and urbanization in regional levels, for instance, in Asian countries, in determining the possible necessary sufficient/efficient energy policies (Bilgili et al. 2017a, 2017b). The regions, i.e., European region, on the other hand, will be successful in energy policies, as other conditions are being constant when they have been converging in the usages of, e.g., convergence in relevant renewables (Bilgili 2012).

The natural gas from shale wells is neither renewable nor conventional and is an unconventional energy source. Although natural gas is considered cleaner than the coal and fuel, the effect of natural gas from shale deposits should be searched thoroughly. Therefore, shale gas exploration may not be considered a clean energy source since it is not free from environmental degradation due to its high energy intensity and high amounts of CO_2 or hydrogen sulfide (Nikiforuk 2013; Huang et al. 2017).

The output of this paper, hence, might also be of interest to authorities, stakeholders, shale gas companies, and policymakers in other states of the US and/or local economies of other countries which have rich shale gas resources.

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