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Making the Best of New Energy Resources in the United States

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MAKING THE BEST OF NEW ENERGY RESOURCES IN THE UNITED STATES

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By Douglas Sutherland

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ABSTRACT/RESUMÉ

Making the best of New Energy Resources in the United States

Since around 2007, the country has been enjoying an "energy renaissance" thanks to its abundant stocks of shale oil and gas. The resurgence in oil and gas production is beginning to create discernible economic impacts and has changed the landscape for natural gas prices in the United States, boosting competitiveness. In order to reap the benefits fully, significant investment is needed. Federal and state governments capture some of the resource rents, but there are potential opportunities to increase taxation and use the revenues to support future well-being. Taxing natural resource rents with profit taxes can be less distortionary than other forms of taxation, though only one state uses this form of tax. Production of shale resources, like other forms of resource extraction, poses a number of challenges for the environment. Respecting demands on water resources requires adequate water rights are in place while state and federal regulators need to monitor the environmental impact of hydraulic fracturing closely and strengthen regulations as needed. Natural gas is a potential "bridge fuel" towards a lower carbon economy, helping to reduce emissions by leading to a substitution away from coal. Flanking measures are desirable to counter natural gas hindering renewables and low prices stymieing innovation.

This Working Paper relates to the 2014 OECD Economic Survey of United States (www.oecd.org/eco/surveys/economic-survey-united-states.htm).

JEL classification codes: H25; Q33; Q35; Q4; Q53; Q58

Keywords: resource taxation, resource booms, hydrocarbon resources, energy, air and water pollution, government policy

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Capital naturel aux États-Unis

Les États-Unis possèdent un riche capital naturel. Depuis 2007 environ, le pays connaît une « renaissance énergétique » grâce à ses abondantes réserves de pétrole et de gaz de schiste. Le nouvel essor de la production pétrolière et gazière commence à avoir des effets économiques perceptibles et a changé la situation des prix de l'énergie aux États-Unis, stimulant la compétitivité. Pour tirer pleinement parti de cette évolution, il faudra des investissements significatifs. Le gouvernement fédéral et les États devraient capter une partie de la rente des ressources naturelles et mettre ces recettes au service de l'amélioration du bien-être futur. Alors que la taxation des rentes de ressources via l'impôt sur les bénéfices peut être moins distorsive que d'autres formes de fiscalité, seul un État y a recours. La production de pétrole et de gaz de schiste s'accompagne d'un certain nombre de défis environnementaux. Pour respecter les demandes d'utilisation des ressources en eau, il faut veiller à l'existence de droits sur l'eau appropriés, et les autorités chargées de la réglementation au niveau fédéral et à celui des États doivent surveiller de près les répercussions environnementales de la fracturation hydraulique et renforcer la réglementation autant que nécessaire. Le gaz naturel peut être une « énergie relais » dans la transition vers une économie sobre en carbone et contribuer à réduire les émissions en entraînant le remplacement du charbon. En l'absence d'une action concertée, il y a toutefois un risque que le marché de l'énergie se reporte de nouveau sur le charbon en cas d'épuisement des réserves de gaz naturel ou de modification des prix relatifs. Des mesures d'accompagnement seraient souhaitables pour éviter que le gaz naturel freine le développement des énergies renouvelables et que la faiblesse des prix paralyse l'innovation.

Ce Document de travail se rapporte à l'Étude économique de l'OCDE de États-Unis 2014 (www.oecd.org/eco/etudes/etats-unis.htm).

Classification JEL : H25; Q33; Q35; Q4; Q53; Q58

Mots-clés : impôts sur les ressources, le boom des ressources, ressources en hydrocarbures, énergie, pollution de l'air et de l'eau, politiques publiques

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MAKING THE BEST OF NEW ENERGY RESOURCES IN THE UNITED STATES

by Douglas Sutherland[1]

The United States is endowed with an abundance of natural capital - the natural resource inputs and environmental services for economic production - and economic growth has been punctuated by periods of their rapid exploitation, such as for gold and other metal ores, minerals and coal, oil and gas. Since around 2007, the country has been enjoying an "energy renaissance" thanks to its abundant stocks of shale oil and gas being made accessible by the combination of hydraulic fracturing and horizontal drilling technologies. The renaissance has revived production of oil and natural gas and is creating economic benefits. At the same time, exploiting natural capital raises issues about how to make sure that the environmental impacts and safety concerns are taken into consideration (i.e. internalise associated environmental externalities) and ensure that longer-term sustainability, both of wealth and the environment, is taken into consideration. This chapter, examining the recent upswing in oil and gas production, considers the policies that help capture the full economic and environmental benefits while addressing externalities and longer-term sustainability.

The next section describes the resource endowment in the United States and how shale oil and gas have changed the picture for the energy sector. The next section discusses the economic benefits which may emerge as a result of increased oil and gas production. The following section assesses how the rents from the sector are being distributed and how taxation of the sector is implemented. This is followed by a discussion of the local impacts of hydraulic fracturing and the regulatory challenge they create. The final section then discusses the contribution natural gas could make to climate change mitigation and the challenges it may pose moving towards an even lower carbon economy.

The United States is well endowed with natural resources

Natural capital represents a relatively small share of the overall wealth in the United States, which is dominated by intangibles or human (and health) capital (Arrow et al.2012). However, on a per capita basis, calculations for the early 2000s still rank the United States 11th in the world according to the abundance of natural capital and 15th in respect to sub-soil mineral resources (World Bank, 2006). Only a few OECD countries have large shares of natural resources as a share of total wealth, which in the case of Norway arises due to their ample off-shore hydrocarbon reserves. Japan, on the other hand, has very few natural resources and its wealth is derived from human capital and produced (physical) capital.

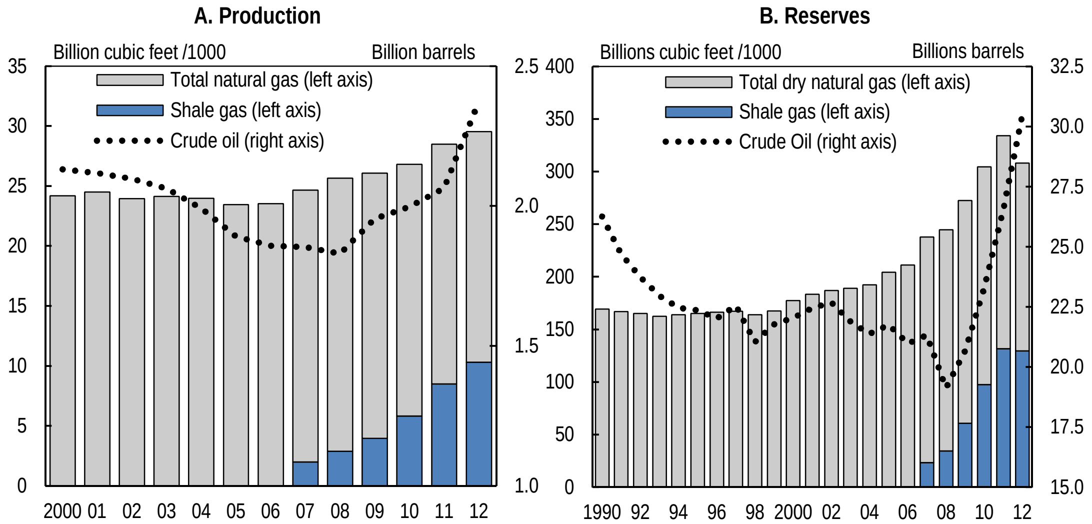
1. Economics Department, OECD. This paper was originally prepared for the OECD Economic Survey of the United States published in June 2014 under the authority of the Economic and Development Review Committee. The annex to the working paper is one of the technical background papers. The author thanks Peter Borkey, Greg Briner, Aida Caldera Sanchez, Anthony Cox, Robert Ford, Justine Garret, Nick Johnstone, Chris Kaminker, Katia Karousakis, Joop de Knecht, Patrick Lenain, Alvaro Pereira, Rodrigo Pinto Scholtbach and Rob Youngman for their comments and suggestions. Special thanks go to Valery Dugain for research and Heloise Wickramanayake for assistance in preparing the document.

Following the successful deployment of new technologies for advanced drilling, the Energy Information Administration markedly increased its estimates of oil and gas reserves (Figure 2.1). Shale gas proved reserves - those reserves with reasonable certainty to be recoverable from known reservoirs under existing economic and operating conditions - have risen more than fivefold between 2007 and 2011 and now account for 40% of total gas reserves in the United States. In the case of oil, shale oil (often referred to as “tight oil”) proved reserves have also risen, though less spectacularly, and these deposits now account for around 10% of total oil proved reserves. Forecasts suggest that production of shale gas will continue to grow strongly till at least 2040 when it will account for one half of natural gas produced in the United States (EIA, 2013). President Obama in his 2012 State of the Union address noted that recoverable resources may last as long as 100 years at current production levels. At present, not all recoverable resources would be commercially viable to extract, but in the longer term as energy prices rise and/or technological innovation reduce extraction costs a greater share of these resources could be extracted. The picture for production of shale oil is similar, but with total oil production peaking before 2030 and then declining.

Natural capital in the United States has been boosted by rises in estimates of proved reserves of shale oil and shale gas. Using a methodology developed by the World Bank to estimate natural wealth gives some indication of the potential changes arising from these developments. By this measure, oil and gas wealth in the United States grew from around 16% of GNI in 2000 to over 30% of GNI in 2008, just when the shale boom was beginning to take off (Table 1). Assuming the boost to reserves extends the resource life, the expansion of shale oil and shale oil production could lift wealth derived from oil and gas substantially. While more recent information on production costs is unavailable, using the latest available figure to estimate the rents suggests that the natural wealth due to gas has fallen somewhat, partly as a result of the falling natural gas prices in the United States (see below), whereas the wealth due to crude oil rose further.

The impact of shale oil and gas development has seen the gradual fall in crude oil production reversed and the production of natural gas pick up. Between 2008 - when production hit its recent low - and 2013 crude oil production has surged, rising by almost 50%. Over the same period, the production of natural gas has risen almost 20%, with shale gas production more than tripling and offsetting declines in conventional natural gas production from other sources.

Figure 1. **Production and reserves of oil and natural gas are rising**



Source: US Energy Information Administration (EIA) and the US Bureau of Labor Statistics.

Table 1. **Estimates of oil and gas wealth**

	2000	2008	2008	2012
Assumed resource life	20	20	40	20
Year of estimated production costs	2000	2008	2008	2008
Natural gas				
Wealth as % of GNI	9.5	16.9	30.8	14.3
Wealth per capita, current USD	3 061	7 977	14 566	6 592
Crude oil				
Wealth as % of GNI	6.9	16.1	29.7	24.3
Wealth per capita, current USD	2 229	7 624	14 055	11 305

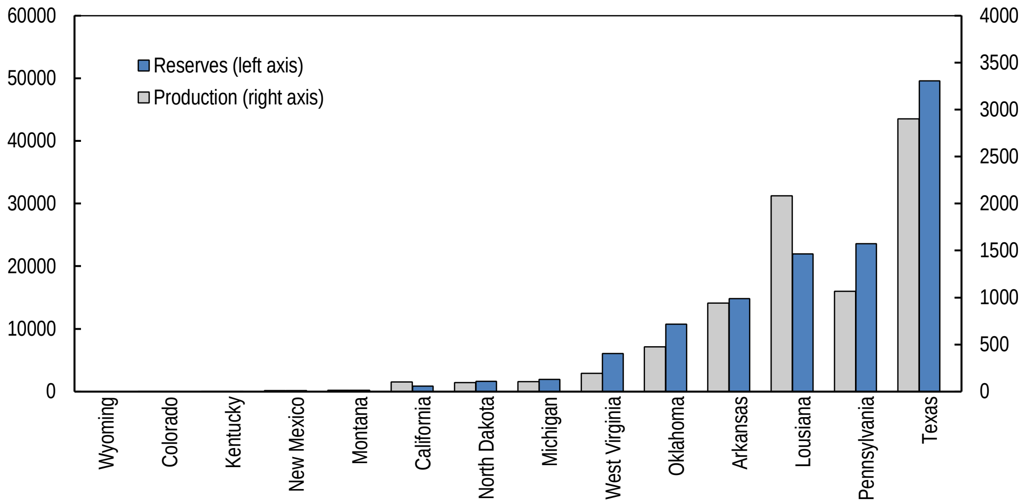
Note: Estimates of oil and gas wealth are based on the methodology used in World Bank (2006). This methodology makes a number of simplifying assumptions to calculate the resource rent. These include setting the assumed resource life of the deposit and estimating of production costs for oil and gas. The calculation of wealth is then based on these parameters and production levels. The table in the first two columns reproduces the estimates of oil and gas wealth for 2000 and 2008 using this methodology. In order to explore the possible impact of more abundant oil and gas resources, the third column reports estimates of wealth when the assumed resource life if doubled. The impact of price changes between 2008 and 2012 is reported in the fourth column.

Source: calculations based on World Bank, EIA, Census Bureau and BEA data.

The oil and gas boom has boosted the fortunes of a number of states and invigorated companies working in the sector. The distribution of shale gas deposits across the country is quite widespread, though the proved reserves are predominantly located in a handful of states, which is also where large-scale shale gas production (these areas are often called "plays") is located (Figure 2). The shale oil deposits are predominately located in Texas, North and South Dakota, Montana, Colorado, Kansas, Nebraska and Wyoming. Whilst energy stocks have tracked the recovery of stock market indices following the crisis, the relatively small scale of hydraulic fracturing wells has led to a substantial inflow of independent companies into drilling and supporting services. As a consequence, the major integrated energy companies have had a less dominant role in the energy renaissance as it got underway, but have increasingly moved into this area.

Figure 2. **Shale gas reserves and production are concentrated in a few states**

Billion cubic feet, Reserves 2011, Production 2012



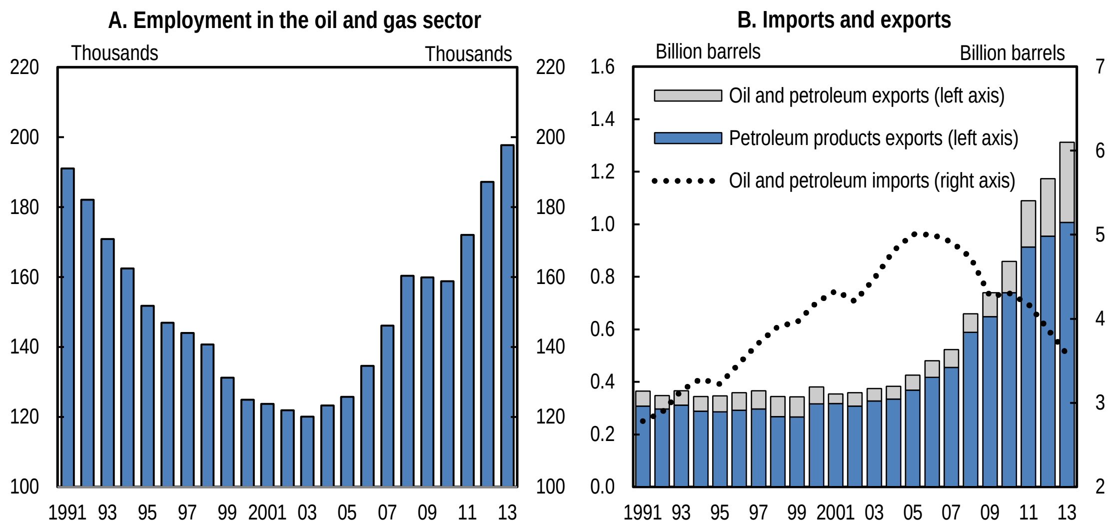
Source: Energy Information Administration.

Capturing the economic benefits

Substantial economic benefits are beginning to arise from hydraulic fracturing

The resurgence in US oil and gas production has already created discernible economic impacts, boosting employment in the sector and exports of natural gas and (particularly) refined products (Figure 3). Other economic benefits are likely to arise as new production serves as a cushion to price volatility. The direct effects of the oil and gas mining sector on growth have been relatively modest, boosting GDP growth by on average by around 0.15 percentage points since the pick-up in energy production began in 2007. However, BEA data on value-added of the oil and gas mining industry show that the sector has picked up dramatically in 2011 and 2012 when the real growth rate of value added in the oil and gas mining sector rose to 7% and then 18%, accounting for 0.23 and 0.35 percentage points of overall GDP growth during these years, respectively. In addition, there are indirect upstream and downstream effects on GDP that are not included in these estimates. The boom in shale oil and gas has contributed to strong investment in structures in the oil and gas sector, with the growth rate in investment recording double digit rates and averaging 18% annual growth between 2010 and 2012. Employment in oil and gas mining remains relatively small, but rising strongly during the recovery from the crisis (Figure 3). Including support activities in the mining sector suggests that employment has been boosted by 300 000 between the nadir in employment in 2003 and 2013.

Figure 3. **The shale boom is boosting employment and net exports**

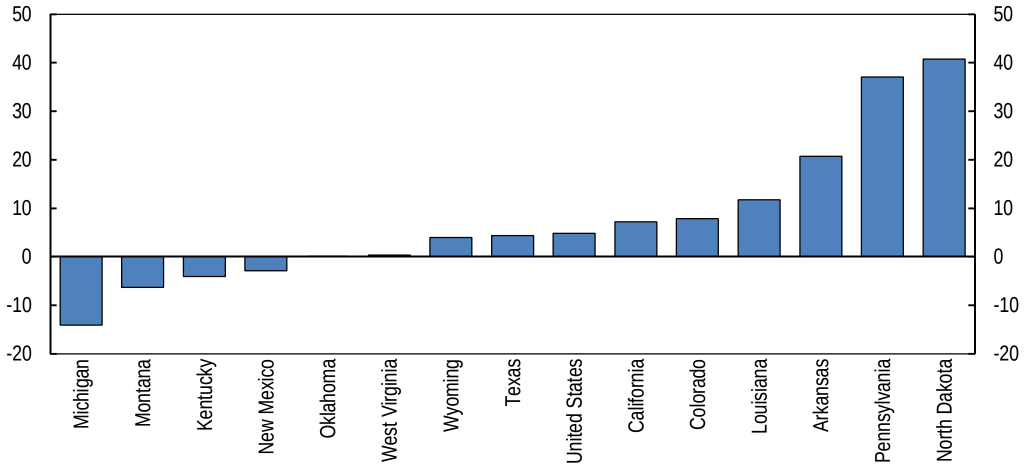


Source: US Energy Information Administration (EIA) and the US Bureau of Labor Statistics.

In the states with the largest shale gas production, the growth rate of the oil and gas mining sector has in some cases been spectacular, with Pennsylvania and North Dakota experiencing annual growth rates in the sector of over 30%, albeit from low initial levels (Figure 4). The effects are discernible in wage and employment developments in some states. The impact of the resource boom is especially apparent on wage growth. For example, according to BLS data, average weekly earnings in North Dakota are rising at a 7% rate since 2011, compared with the national average of around 2%. BLS data also show that gains in mining sector employment have contributed to sizable employment gains in a number of regions.

Figure 4. **Growth in the oil and gas mining sectors is fast in some states**

Average growth rate 2007 to 2011

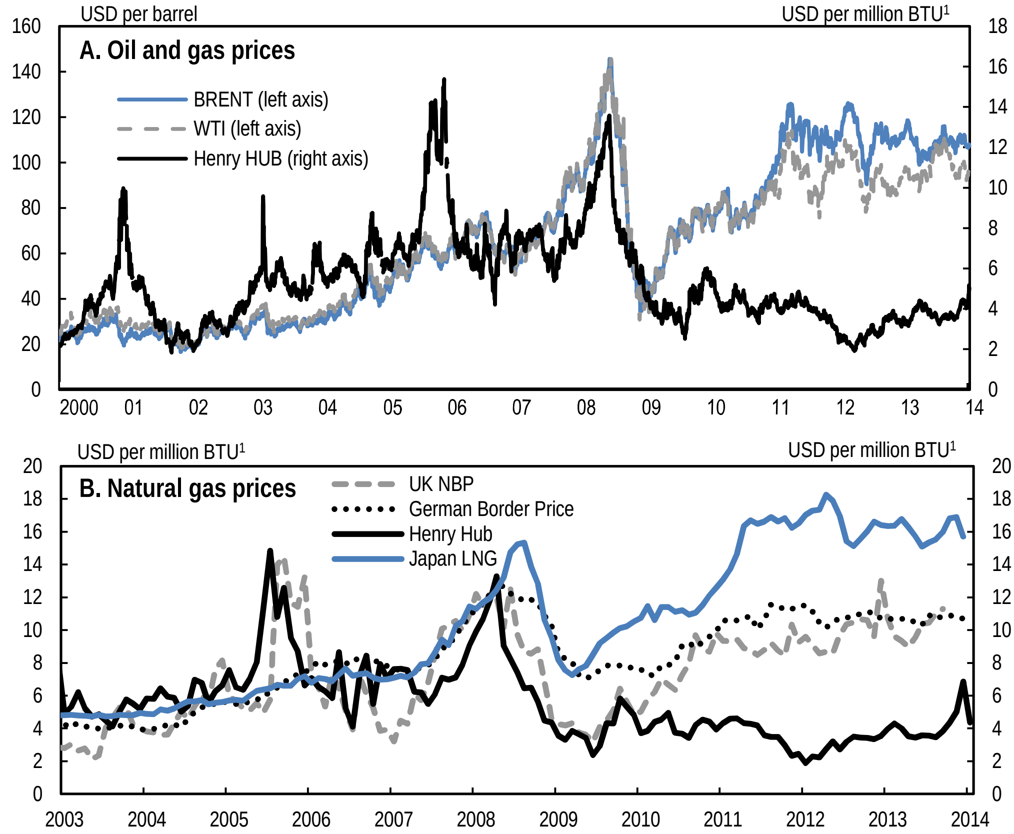


Source: Bureau of Economic Analysis.

The oil and gas boom has depressed domestic energy prices

The shale gas and oil boom has changed the landscape for energy prices in the United States. The relationships between international oil prices (Brent), domestic oil prices (WTI) and natural gas prices (Henry Hub) have weakened, with the tendency for these prices to move together becoming weaker after mid-2008, largely coinciding with the largely unanticipated rapid pick up in shale oil and gas production (Figure 5). The decoupling of natural gas from prices in Europe and Asia is particularly pronounced. The price of natural gas fell to as low as around one-quarter of natural gas prices in Europe and even less in the Asian market before rebounding somewhat. The low price of natural gas promoted a switch in exploration and production away from shale gas and towards shale oil. Lower domestic natural gas prices have supported natural gas exports and are boosting the potential competitiveness for natural gas intensive industry by reducing feedstock (mainly ethylene) prices, whereas other sectors benefit from cheaper energy prices. Given liquefaction, transportation and regasification costs, the wedge between domestic and international natural gas prices is likely to be persistent. Export of natural gas to countries without free-trade agreements with the United States requires prior approval from the Department of Energy, for which there is an established authorisation process. The Administration should ensure that energy exports are promptly approved. Limited export-oriented infrastructure also currently constrains natural gas exports. Although more than 9 billion cubic feet per day of export facilities have been granted conditional permits from the Department of Energy and roughly 2 billion cubic feet per day have received final permits, LNG export facilities are massive and require years to construct. With the prospect of lower domestic energy prices, investment in pipelines and other transportation infrastructure, which are undertaken by the private sector, will be important to ensure the economy can reap the full benefits.

Figure 5. **Oil and gas prices have diverged**



1. BTU (British Thermal Units)

Source: Bloomberg and International Energy Agency.

In the oil sector, legal restrictions on crude oil exports in place since the 1970s do not prevent the exports of refined petroleum products. However, foreign sales may be limited to the extent that refining capacity and transportation infrastructure are insufficient to handle the available supply. The Administration is considering options under current law to allow exports of crude oil. Another approach would be to abolish the prohibition of crude oil exports altogether.

Other sectors will benefit from the expansion of hydraulic fracturing through input-output linkages. The demand from the development of the shale gas and oil sector to other sectors is likely to be relatively weak. On the other hand lower energy costs can raise the competitiveness in energy intensive sectors, augmenting the impact of relatively modest growth in unit labour costs (Celasun et al., 2014). The impacts on energy-intensive sectors, such as chemicals, are currently limited (Goldman Sachs, 2013). To some extent, the lack of a consistent picture in industries most likely to benefit from low domestic energy prices is due to their capital-intensive nature. As new capacity takes time to construct the full impact on competitiveness will only become apparent over time. That said, recent data suggests that the low domestic energy prices are having an impact on exports. For example, Spencer *et al.* (2014) note that net exports in energy-intensive sectors more than doubled in value between 2006 and 2012 to USD 27 billion, though still only accounting for a small share of overall trade. While the effects outside the oil and gas mining sector have been relatively small so far, the potential for larger effects nonetheless exists (McKinsey, 2013).

In order to reap the benefits fully, significant investment is required. This includes investments in hydraulic fracturing and drilling itself, pipelines and other transportation infrastructure, reorienting import terminals to export terminals and the expansion of energy-intensive industries that are likely to benefit from lower prices. Given the significant sunk costs and irreversibility associated with these investments, measures that reduce uncertainty support the development of transportation and associated infrastructure. In this context, a stable policy regime, including for climate change (see below), acquires some importance. As discussed below, the environmental impact of hydraulic fracturing is not well understood, which creates uncertainty as to the likely regulatory response. In these circumstances, companies may adopt a wait-and-see strategy and delay investment while environmental agencies develop their regulations. The regulatory approach to the development of natural resources is likely to vary considerably across states, covering environmental standards as well as permitting and licensing. Rahm (2011) notes that the development of mineral rights in some states, such as Texas, is comparatively straightforward whereas in others areas, such as New York state and a number of localities, development is explicitly prohibited. The federal authorities become important regulators when resource development requires interstate transport, with pipelines requiring the approval from the Federal Energy Regulatory Commission.

Who is capturing the benefits?

The boom in oil and gas production is having significant effects in the states were the deposits are located. This raises two related issues. The first concerns how the gains from oil and gas exploitation are shared. The second is what happens after the oil and gas deposits are exhausted. In this context, governments by capturing some of the resource rent can address how to adjust once the resource boom has run its course. This could take the form of investing in education, including community colleges to help workers become more adaptable, funding research, financing productive infrastructure provision and establishing endowment funds and putting government finances on a better footing by paying down debt. In some senses, due to the fungibility of money, ensuring that policy avoids squandering the revenues is key to securing longer-term welfare.

Natural resources confer natural rents, which is roughly the difference between the price at which the resource can be sold less the costs of exploitation and extraction or more formally the opportunity cost of holding the resource underground. Policy settings are important in determining which groups benefit most from the exploitation of natural resources, including future generations who stand to lose unless provisions ensure they also benefit.

In competitive markets, the benefits of resource exploitation are shared among several parties. First, landowners benefit from owning the mineral rights through lease payments for their exploitation. Second, new gas and oil production has pushed down energy prices, particularly gas prices, benefitting consumers. In the oil sector, legal restrictions on crude oil exports in place since the 1970s do not prevent the exports of refined petroleum products. However, foreign sales may be limited to the extent that refining capacity and transportation infrastructure is insufficient to handle the available supply. For example, some refiners are better adapted to using heavier crude oil than the light oil typically produced by hydraulic fracturing. In this case, some of the possible resource rent obtainable for oil producers though exporting would be sacrificed were domestic light oil production to rise to the point where it exceeds domestic refiners' ability to easily absorb it. The Administration is considering options under current law to allow exports of crude oil. Another approach would be to abolish the prohibition of crude oil exports altogether.

Taxation of shale oil and gas

Federal and state governments may capture some of the resource rent through various taxes and use the revenues to support spending or funds that will raise future well-being. Taxing natural resource rents, if done properly, can be less distortionary than other forms of taxation (Box 1.). A well-designed profit tax could reduce economic distortions which can discourage exploration and development. However, most governments rely on royalties and the rate applied can be relatively low. A few states have experienced a significant increase in revenues from resource related taxation (Table 2) and enjoyed a corresponding boost to spending (NASBO, 2013).

Box 1. **Taxation of non-renewable natural resources**

Profits derived from non-renewable resource extraction can be taxed while imposing relatively small distortions on the economy (Andrade de Sá and Daubanes, 2014). However, the form of taxation can influence the effort in exploration and development. While a number of options exist for taxing resources rents, in the United States, most governments rely on royalties (also known as severance taxes). Due to the split between federal and state tax authority, combinations state resource taxes and federal corporate income taxation are typical.

Royalty taxes are based on the amount of oil and gas extracted. While relatively easy to collect they introduce a number of distortions. The tax can induce the firm to shut extracting the oil and gas earlier than is socially optimal. Secondly, the tax can reduce incentives to invest in exploration, although this can be mitigated partially by offering investment subsidies. Broadway and Keen (2008) point out that this may give incentives for state governments to levy higher severance tax rates than they otherwise would if the royalties are deductible against federal corporate income tax. The range of rates levied across the states suggests that this is not an overriding concern. Profit taxation is another approach (implemented in Alaska in combination with a royalty tax), which is intended to capture a share of profits arising from the resource rent. In this approach a tax is levied on all real transactions on a cash flow basis. The government reimburses the private sector firm for negative cash flows, which are typical in the early stage of a project, and retain a share of total revenue when the project is generating a positive cash flow. In practice, governments find it hard to compensate a private sector firm contemporaneously and prefer to allow the private company to carry forward losses with interest. This form of taxation can potentially capture a large share of the resource rent without distorting investment and production decisions. Furthermore, the tax base is likely to differ from the resource rent and will again introduce distortions to investment and production decisions, though they are less severe than royalty tax regimes. A final approach is through using fixed fees for exploration and auctions for exploration rights to capture some of the resource rent. When other forms of taxation are also levied later on the project life, the amount of rent captured will be reduced or the fee will discourage investment.

The taxation of oil and gas resources in the United States varies depending on the ownership of the land with the deposit. As the majority is on private land, the federal government has little influence on the taxation of these resources other than through the normal application of corporate income taxes, which is determined by Congress. When oil and gas deposits are on federal land, taxation on mineral resources is implemented by the Department of the Interior. The Department of the Interior (ONRR) collects revenues when bids for leases are made (bonus bids), rent while the lease is not in production (rental fees) and royalties when production starts (royalties). Following criticism from GAO over the low federal government take (GAO, 2013), the Department of Interior changed offshore terms (royalty rates set at 18.75% for some offshore deposits, minimum bids, rental rates), but has not changed the onshore fiscal system (royalty rate of 12.5%). For deposit on federal land, the states also get a share of the revenues from the royalties. The split is 50-50 between the state and federal governments with the exception of resources lying on the outer continental shelf for which the revenue split for littoral state governments is 27% or 37.5% under the Gulf of Mexico Energy Security Act.

For oil and gas deposits on private or state owned land, there is no consistent tax treatment across the states. Taxes on production as a share of the oil and gas sector's value added ranges from just 7% in Arkansas to almost 60% in Alaska (Table 2). Royalty tax revenues accrue totally to the state if the land is privately held. Different royalty taxes are in place in 30 states, ranging from 10 cents on the barrel for oil in Ohio to 8% of gross value in Kansas. Alaska implements a hybrid system combining a royalty tax and a profits tax, which has more desirable properties. Pennsylvania, the third largest producer of shale gas in 2011, does not levy a specific tax. However, Pennsylvania introduced an unconventional gas well fee in 2012. If revenues exceed a threshold, surplus revenues will be distributed to localities. At the local level, states may share some of the royalty tax revenue with local governments. In addition, hydraulic fracturing rents are taxed through property and/or income taxes. In some cases, property taxes include mineral rights in the base. Consistent with the theoretical analysis of royalty taxation, the development of reserves tends to be depressed by higher rates of royalty taxation on value added (see Annex).

Table 2. **Tax revenue from oil and gas**

Selected states with significant shale gas production

	Taxes on production as % of state GDP		**Taxes on production as % of value added**	**All royalty taxes as % of state GDP**	
	2007	**2011**	**2011**	**2007**	**2011**
Alabama	0.1	0.1	17.4	0.1	0.1
Alaska	7.1	10.4	58.1	5.5	11.2
Arkansas	0.0	0.1	7.0	0.0	0.1
California	0.1	0.1	11.8	0.0	0.0
Colorado	0.4	0.5	20.9	0.1	0.1
Kentucky	0.0	0.0	41.9	0.2	0.2
Louisiana	0.7	0.7	8.7	0.4	0.4
Michigan	0.0	0.0	27.1	0.0	0.0
Montana	0.2	0.2	26.4	0.8	0.8
New Mexico	1.6	1.4	27.9	1.3	1.0
North Dakota	0.3	0.4	16.5	1.4	6.9
Ohio	0.1	0.0	30.3	0.0	0.0
Oklahoma	1.3	1.2	17.0	0.7	0.5
Pennsylvania	0.0	0.1	15.3	0.0	0.0
Texas	1.2	1.1	16.1	0.2	0.3
West Virginia	0.3	0.2	25.3	0.6	0.9
Wyoming	3.2	3.2	23.7	2.4	2.5

Note: Royalty taxes are all royalty revenues, not just those accruing from oil and gas mining.

Source: BEA, Census bureau

Future generations

One challenge is to ensure that current resource use also supports economic welfare of future generations. On aggregate for the United States, estimates of adjusted net savings, which take into account whether total wealth (including natural resources) is increasing, suggest that investment in education outweighs the depletion of natural resources (Box 2). Using revenues to support future living standards differs across the states. Some such as Alaska, Colorado, Montana, New Mexico and Wyoming have created severance endowment funds, which *inter alia* use revenues raised from oil and gas exploitation to help finance capital projects and invest in education. For example, West Virginia created a Future Fund, capturing 3% of the severance tax to fund infrastructure, education and economic development as well as tax relief and cultural preservation. The fund created limitations on how much lawmakers could draw on the fund (SWF Institute, 2014). The New Mexico Severance Tax Permanent Fund uses its resources to pay interest in bonds financing capital projects also investing in education. Other states have earmarked natural resource revenues to support spending that is less likely to benefit future generations. For example, West Virginia did not establish a specific mechanism to ensure future generations also benefitted from the mining of its substantial coal deposits. Rather revenues were spent annually. As coal mining in the state has weakened, the state is facing challenges in adapting to this environment (Williams, 2008).

Box 2. **Natural resources and economic sustainability**

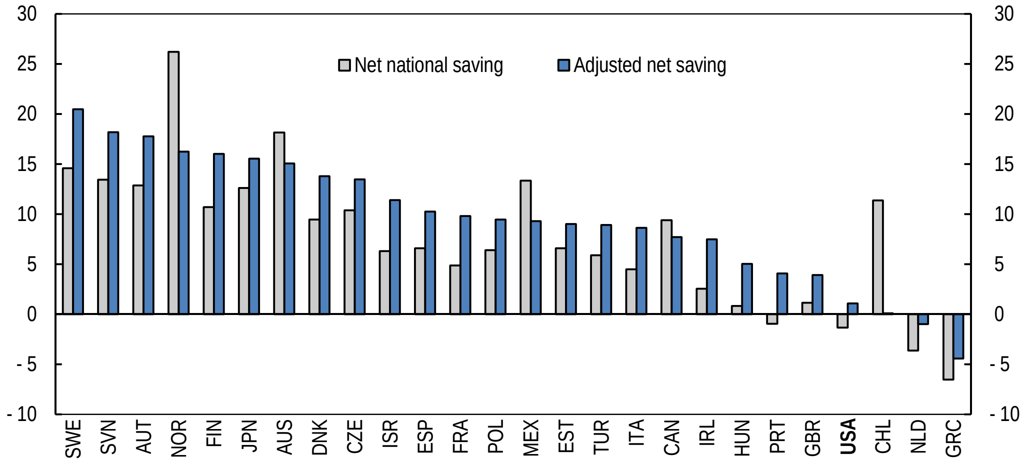
Non-renewable natural resources once (economically) recoverable will be *ceteris paribus* depleted. As such the country's stock of (natural) wealth is reduced, with the exploitation akin to a process of disinvestment. As such future generations are not guaranteed to share in the benefits of these natural resources. This has led some authors, such as Hartwick (1977), to recognise that investing the rents captured during the depletion of the exhaustible natural resource in (produced) capital can enhance sustainability. That is, not only the current generation enjoy the benefits from resource exploitation, but future generations also enjoy raised consumption possibilities. However, the degree to which natural and produced capital stocks are substitutable is not always clear cut and in some cases the amount of natural capital needs to be preserved above critical levels in order to provide environmental services that may provide life-support functions.

Identifying empirically whether the current patterns of natural resource exploitation is sustainable presents a number of difficulties in both the measurement of natural capital and identifying which types of investment will augment future generation's stock of wealth. Standard measures of economic development, such as GDP growth and measures of capital stocks generally do not consider the role of environment in production. A number of approaches have taken into account the environment.

- One approach has been to adjust the standard measure of national savings by the depletion of natural resources and the impact on environment. The so-called genuine savings or adjusted net saving assess whether the exploitation of natural resources (and environmental externalities) does not subtract from economic welfare of future generations (World Bank, 2006). Updated estimates for 2008 suggest that for the United States that net savings (gross national savings minus consumption of fixed capital) was negative. However, adjusted net saving was positive when taking into account education spending and making adjustments for the depletion of energy and mineral resources and environmental damage from carbon dioxide emissions and particulate matter. Nonetheless, savings in the United States were comparatively small by both measures (Figure 2.6).

Figure 6. **Adjusted national savings (2008)**

As a percentage of GNI

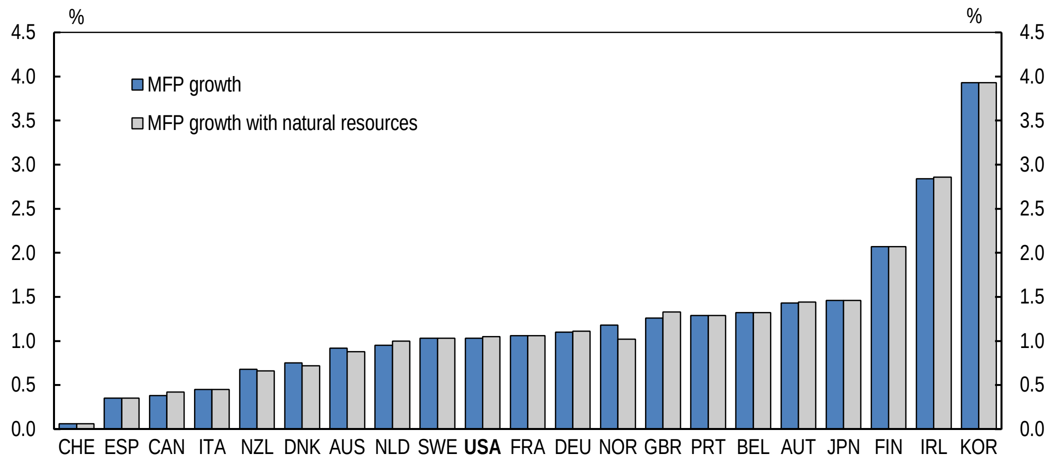


Source: World Bank.

- Related and recent work at the OECD has attempted to take account of the use of certain types of natural capital through adjustments to productivity measures (Brandt et al., 2013). This work (covering the period 1986 to 2008) suggests for the United States that the difference between traditional and adjusted productivity measures is not large (Figure 7). However, during this period, oil and gas reserves fell and the contribution of natural capital to growth was slightly negative overall. As such, during the period of resource depletion, other factors of production needed to increase slightly to maintain similar rates of growth.

Figure 7. **Average annual productivity growth with and without natural capital**

Based on data from the OECD Productivity Database, 1986-2008



Note. The MFP growth with natural resources is derived by extending a standard production function with measures of natural resource flows and estimates of their associated unit costs.

Source: Brandt et al. (2013).

In a number of cases, governments also collect revenues for conservation and remediation purposes. At the federal level, the Land and Water Conservation Fund (LWCF) was introduced in 1964 to capture some of the rent from the depletion of oil and gas resources on the outer continental shelf to protect other natural resources, such as coastal areas, open areas and wildlife habitat. At the state level, a few states levy taxes to address oil field clean ups and restoration, including Louisiana and Texas. Several other states levy oil and gas conservation fees which are earmarked for capping and reclaiming abandoned wells amongst other uses.

Local impacts

Hydraulic fracturing has aroused considerable controversy. The environmental and social impact of large scale drilling activity across the landscape has provoked significant local opposition in some parts of the country. Bans have been imposed in New York State, metropolitan Pittsburgh and a handful of towns around the country. However, survey findings reveal respondents are not necessarily opposed to hydraulic fracturing, but want assurances that it will be conducted correctly (Krupnick, 2013), implying a role for regulatory frameworks in facilitating stakeholder acceptance (IEA, 2012).

Local externalities

At the local level, inhabitants experience a number of externalities (Muehlenbachs et al., 2012). Close to the well inhabitants face (adjacency) costs associated with noise and light pollution, local air pollution, visual dis-amenities (pollution). In addition, there are a number of vicinity effects as people are affected by the impact of traffic congestion and road damage as the road pavement in rural areas are often not constructed for the heavy vehicles. The major impacts for residents are arguably through the environmental externalities created by hydraulic fracturing. There is considerable uncertainty about these effects and the science far from settled. The impact on the local environment is not universally negative. The substitution of coal and other fuels by natural gas may have effects through reducing other emissions, such as sulphur dioxide, carbon monoxide, nitrous oxides and particulate matter.

Hydraulic fracturing puts stress on water resources…

Up to 5 million gallons of water are needed for each shale gas hydraulic fracturing well. This demand in a relatively short period of time puts stress on local water resources, which is not limited to a problem of arid regions. Demands on water resources have mounted and water stress has become a more common phenomenon. The rate of extraction of ground water from aquifers has increased over the 20th century, partly driven by land drainage to extend farmland. Since the turn of the 21st century, the rate of ground water depletion has accelerated, such that slightly less than one-fifth of total groundwater depletion since 1900 occurred in the period 2000-08 (USGS, 2013). While hydraulic fracturing only accounts for a small fraction of the demand for water, the localised demand for a short period can create important stresses on water resources. For surface water, such demands can threaten the environmental services provided by the local ecosystems when water levels or flows drop precipitously.

Respecting the competing demands on water resources requires adequate water rights are in place, while respecting minimum flow requirements for water bodies. Pricing water resources effectively and allowing trading may go some way to using limited water resources efficiently. Remediation efforts and biodiversity-offsets or compensatory mitigation, which ensure that the environmental damage in one area is compensated in another, can play a role to mitigate excessive stresses on water resources. For example, the EPA has established “mitigation banking” to preserve wetlands. Under this approach, projects that will have unavoidable impacts on wetlands must purchase offset credits to support the establishment, restoration or enhancement of wetlands in a different location, which may be undertaken by a third party. In a similar approach to offsets, the federal government uses royalties from the depletion of oil and gas resources on the outer continental shelf held in the Land and Water Conservation Fund (LWCF) to protect other natural resources. Similarly, the Energy Policy Act of 2005 established the Coastal Impact Assistance Program (CIAP) which provides money for coastal restoration and preservation for littoral states. While the offset approach has attractive properties, care is needed to ensure that there are not non-linearities with the depreciation of natural capital in one location that cannot be offset by supporting natural capital in another (see Dasgupta, 2009 for a general consideration of these issues). In this context, the permitting authority needs to ensure that the proposed project does not have unavoidable (irreversible) consequences, such as contamination of a groundwater aquifer, that outweigh the proposed benefits. When irreversible effects are a concern, the regulatory authority should postpone decisions until new information helps reduce uncertainty about the consequences. Such decisions should also account for the public's preferences for environmental services, which vary across the country. In this context, taking stock of opinions, such as is done by Canada's biennial Household and the Environment Survey, would help better inform decisions concerning the environment at both the national and state level.

… and risks water contamination

Risks from hydraulic fracturing wells include contamination of shallow freshwater aquifer and surface water with chemicals and other substances used or released in the fracturing process. Reports examining the potential for contamination of drinking water suggest that risks to aquifers are low if the hydraulic fracturing takes place at sufficient depth. However, contamination risks stemming from faulty wells and accidental spillage leading to surface water contamination remain (Royal Society, 2012). Groundwater contamination risk remains a major concern expressed by residents. This can also be seen through the effect on property prices. Early evidence, using data from Pennsylvania and New York on house sales and well placement suggests that houses near the wells benefit from economic rents, but within a close radius of 1-1.5 km, the fear of groundwater contamination pushes house prices down (between 10% and 22%) compared to houses that rely on public water supplies (Muehlenbachs et al., 2012). Households may suffer from adjacency effects, which push prices down further next to the wells. Overall the study noted that the benefits from shale gas arrive quickly but then dissipate, consistent with a boom and bust type of development.

Water is often co-produced with hydraulic fracturing, which creates challenges for treatment and disposal, such as separating out and re-injecting in lower appropriate disposal zones. Some of the water introduced in the well (15-80%) will become "flowback", which may need to be treated due to chemicals added to the fracturing fluids as well as the materials mobilised during the fracturing process, such as heavy metals and naturally-occurring radioactive materials. The wastewater may be recycled and used in other wells, re-injected deep underground (often into salinic acquifers), treated and added to surface water or spread over the land. Kiviat (2013) reports a number of incidents where hydro-fracturing fluids have been released into the environment and discusses the implications for biodiversity. Empirical work suggests that the major problems are more likely to be found at the treatment sites than the wells (Olmstead et al., 2013). Fracturing fluids contain chemicals to separate the oil and gas from the rock formations and ease their passage through the rock as well as propping agents which hold the rock formations open to allow the natural gas and oil to flow through the horizontal portion of the well to the vertical portion of the well. Some states have not required the disclosure of what chemicals are being used in fracturing fluids (McFeeley, 2012). However, other states have begun to require industry participants to report which chemicals are being used and voluntary reporting of chemicals is occurring with groups such as Fracfocus and the EPA is seeking public comments on disclosure. While exemptions to public disclosure due to trade secrets can be part of the disclosure regime, these should not become a loophole and companies should be required to report the chemicals being used to a regulatory authority.

The regulatory regime is complex

Regulation on water use and the protection of groundwater and surface waters has originated at different levels of governments, which has resulted in a complex overall regulatory regime. For example, local authorities, groundwater management areas and regional planning bodies are involved in granting access to water resources, and state and federal bodies are responsible for environmental management and stewardship. Most regulation of hydraulic fracturing is issued at the state level, although the Department of Interior can regulate hydraulic fracturing on federal land and EPA has some limited responsibility, which is typically implemented by authorised states, tribes and territories. Under the federal Safe Drinking Water Act, EPA's regulations specify minimum permitting requirements applicable to hydraulic fracturing of oil and gas wells using diesel fuels. The EPA released guidance to state and EPA regional permit writers in 2014. These regulations also apply to underground injection of wastewaters from oil and gas production (irrespective of use of diesel fuels) for purposes of disposal. In addition, under the federal Clean Water Act, EPA's regulations restrict the discharge of hydraulic fracturing wastewater to surface waters under the national technology-based limitations programme. However, federal regulatory authority to address water quality impacts of hydraulic fracturing is limited under several key environmental statutes – for example, the oil and gas stormwater exemption from permitting requirements under the Clean Water Act and the exclusion of hydraulic fracturing (other than where diesel is used) from the Safe Drinking Water Act Underground Injection Control requirements. The federal authorities can also become involved when the EPA issues an endangerment order, which can require a company to take immediate action to protect individuals from harm (Rahm, 2011). Further study is needed to formulate regulation to address environmental concerns and increase public confidence in hydraulic fracturing, notably to harmonise and strengthen the impact assessments of drilling projects.

What happens when things go wrong?

Transportation needs for shale oil and gas have grown rapidly, often in regions where the existing pipeline capacity is insufficient. This has led to a surge in railroad transport, with the number of railroad carloads of crude oil jumping an estimated 42 times between 2008 and 2013 (Association of American Railroads, 2013). Rail in late 2013 accounted for the transport of around 800 000 barrels a day or 11% of total oil shipments. The transport of crude oil by train raises a number of risks. During 2013, a number of accidents, including the explosion in North Dakota, reignited concerns about the safety of this mode of transport, particularly in the aftermath of the Lac Mégantic tragedy in Canada. In this context, measures to help develop pipeline capacity, such as expediting the planning process and reducing uncertainty about projects, would be welcome. However, due to the dispersed nature of drilling, transporting oil to the pipelines will still require other means of transportation. Federal authorities are responsible for setting rail standards while state authorities, such as New York, are drawing up contingencies plans for the possibility of accidents. To some extent, railroad transport is also favoured by the Jones Act, which bans foreign shipping undertaking cabotage in US coastal waters. Railroads are ideally placed to benefit from the lack of domestic shipping capacity.

A second area is what happens in the aftermath of significant environmental damage. After the Deepwater Horizon event, Congress passed the Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies (RESTORE) which channelled penalties levied under the Clean Water Act for coastal restoration. Applying similar approaches for hydraulic fracturing may run into problems. Due to the smaller size of firms involved, the possibility of appealing for bankruptcy can mean that penalties will not cover all damage costs if the firm is found liable and it will not internalising the externalities. Requiring insurance-type payments may lead to riskier behaviour than otherwise. In this context, levying restoration fees, as many states already do to deal with clean-up costs and abandoned wells, while leaving firms liable may be a reasonable approach. Alternatively, regulators could set verifiable precautionary standards backed up by legal proceedings (Hiriart et al. 2004). An alternative approach could be implemented through bonding requirements, which are already used in a number of states and by the federal government. Under this approach, companies post bonds prior to drilling wells. If the exploitation results in no environmental damage the bond is returned to the company when production at the well ceases (Davis, 2014). States with a longer experience of oil and gas production tend to have stricter regulations in place and levy restoration fees or bonds (Richardson et al., 2013).

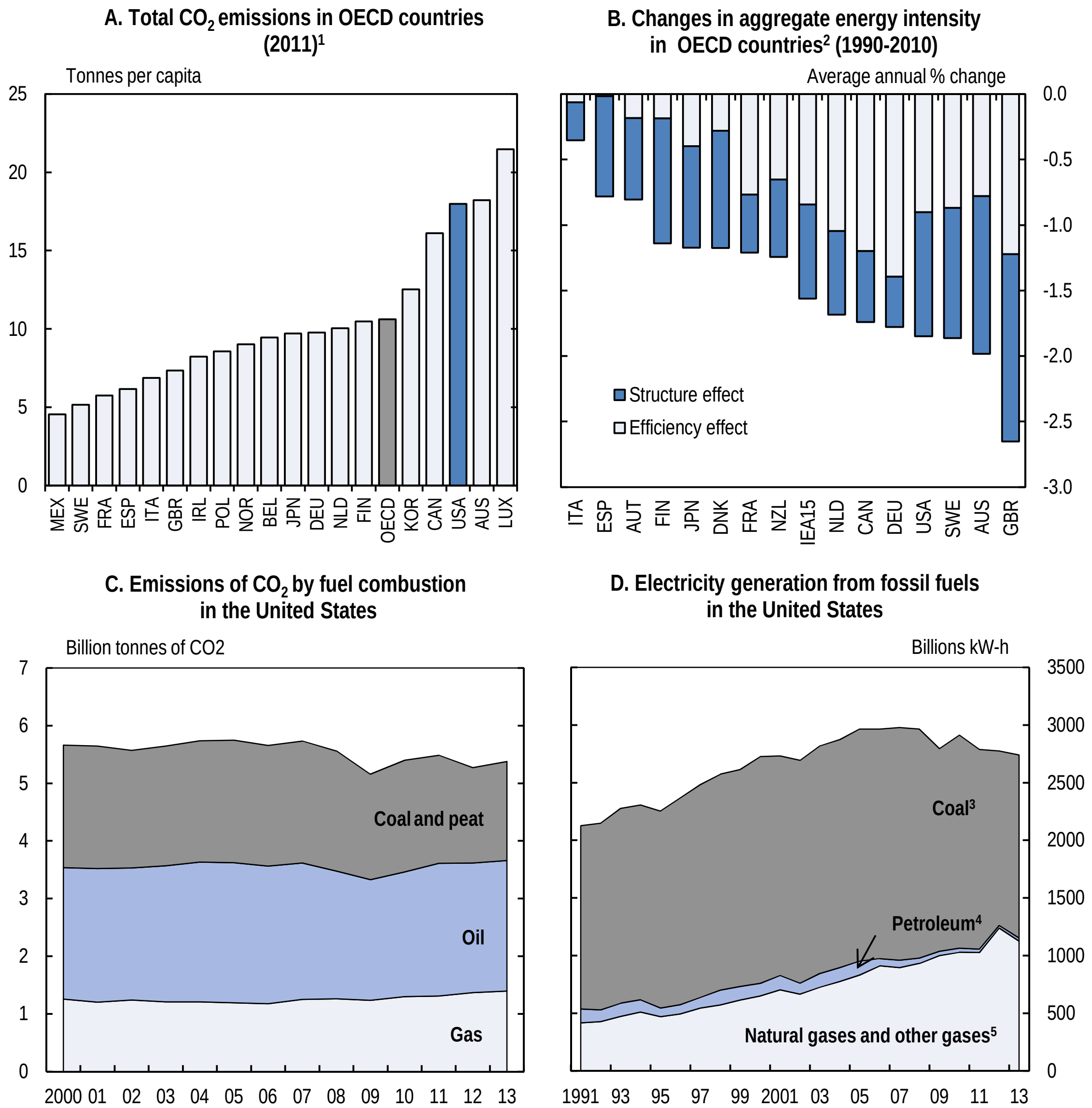
Links to climate change

In 2009, the United States committed to the goal of reducing greenhouse gas (GHG) emissions in the range of 17% from 2005 levels by 2020. There have been sizeable reductions in emissions, partly arising due to the recession as well as to improvements in energy efficiency in the economy (Figure 8). In 2012, carbon emissions from the energy sector fell to the lowest level in two decades. Among OECD countries, the United States has achieved among the biggest improvements in energy intensity in recent decades, albeit from relatively high levels. Its energy intensity declined at an average rate of 2% per year from 1980 to 2010. In recent years, policy efforts to improve energy efficiency further have been reinforced. For example, the 2009 economic stimulus package included new energy efficiency initiatives and substantial additional funding for existing programs. In June 2013, the administration unveiled a comprehensive Climate Action Plan, including a plan to impose carbon emissions standards to both new and existing power plants.

Despite the positive trends, preliminary data show that carbon dioxide emissions are estimated to have risen by around 2% in 2013. During the summer of 2013, higher demand for electricity induced an increase in coal-fired electricity supply and severe winter weather raised energy demand at the end of the year, boosting carbon dioxide emissions and highlighting the interplay between weather conditions and the electricity sector (Box 3).

The current approach to meet climate change objectives relies less on using market-based instruments, such as an emission tax, and more on regulation. In this context, the EPA is charged with regulating greenhouse gas emissions from electricity generation under the Clean Air Act. The states will have flexibility in how to implement these requirements for power plants in their jurisdictions, thereby allowing them to choose locally-appropriate compliance measures. Other initiatives to improve energy efficiency will serve to reduce emissions further. This approach to emission abatement is arguably more costly than an emission tax, though by inducing fuel switching may achieve some reductions at relatively low cost (Goulder et al. 2014). However, with this approach, care is needed to prevent the marginal abatement costs diverging too much. Given the variety of approaches the states are likely to adopt, including market-based cap-and-trade schemes (see Box 4), regulation may be needed to limit differences in the stringency of regulation as well as address possible coordination failures across states. Carefully designed state-level policy has the potential to achieve considerable emission mitigation at relatively low cost (Burtraw et al. 2014).

Figure 8. **Some progress in reducing greenhouse gas emissions**



1. 2010 for Mexico.
2. For the United States, data are mainly compiled and estimated by the IEA based on available sources including IEA energy balances, U.S. Energy Information Administration, U.S. Bureau of Transportation Statistics, Oak Ridge National Laboratory, OECD STAN Database, U.S. Census Bureau and Pacific Northwest National Laboratory.
3. Anthracite, bituminous coal, subbituminous coal, lignite, waste coal, and coal synfuel.
4. Distillate fuel oil, residual fuel oil, petroleum coke, jet fuel, kerosene, other petroleum, and waste oil.
5. Natural gas, plus a small amount of supplemental gaseous fuels. Other gases:
   Blast furnace gas, propane gas, and other manufactured and waste gases derived from fossil fuels.

Source: International Energy Agency and US Energy Information Administration.

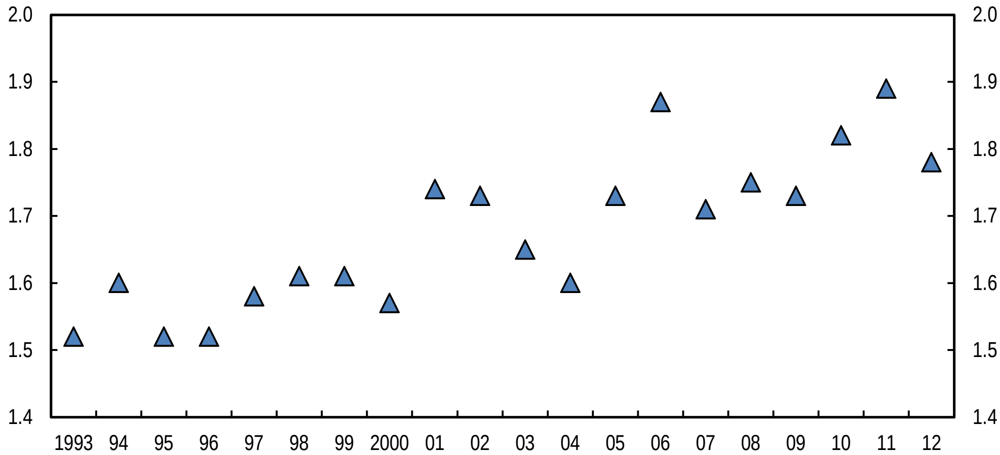
Box 3. **Greater weather variability**

The scientific evidence assessed by the Intergovernmental Panel on Climate Change (IPCC, 2013) points to climate change amplifying extreme weather events, with the effects varying regionally. The types of extreme weather events that are becoming more frequent include longer heat waves and heavier precipitation. In North America the threat of flooding and more intense storms also appears to have risen.

The combination of changing weather patterns with trends in energy demand has had implications for electricity generation. Energy demand has changed as the share of industry in total output has fallen, technology has become more energy efficient and the greater diffusion of air conditioning. These trends have led to electricity demand becoming more weather sensitive such that when weather conditions lead to more use of cooling or heating, demand for electricity surges. Over time as the reduction in consumption from sectoral change and improved energy efficiency has reduced the average demand for electricity, the increasing sensitivity of demand to heating or cooling has seen the ratio of peak to average demand for electricity gradually increase (Figure 9). During the periods of surges in demand, the marginal producer of electricity may change with corresponding changes in fuel type. In 2013, more days had pronounced peaks in temperature which would require cooling in buildings (raising cooling degree days) while the winter in early 2014 was exceptionally cold raising the amount of heating needed to maintain a comfortable temperature in buildings (raising heating degree days). Partly as a result, emissions of carbon dioxide from coal rose by an estimated 2%, reversing some of the gains in emission reductions recorded over the previous five years as previously mothballed coal-fired power stations were brought back on line. Greater weather variability complicates the management of the electricity market and potentially makes climate change mitigation more difficult to achieve in the absence of other measures. To the extent that the weather patterns are becoming more volatile, these challenges may become more difficult to address.

Figure 9. **Variation in electricity demand is growing**

Ratio of peak-to-average electricity demand in New England



Source: Energy Information Administration.

Shale gas can help reduce emissions

Natural gas is a potential "bridge fuel" towards a lower carbon economy. The rapid development of US shale gas resources has helped to reduce emissions by leading to a substitution away from coal-powered electricity generation to natural gas turbines (Figure 7). Indeed, coal-fired power stations have been under pressure from slowing electricity demand and competition from low natural gas prices. Coal-fired electricity generation has fallen by around 11 percentage points of total electricity production between 2008 and 2012, while natural gas accounted for a rise of 9 percentage points between 2008 and 2012, suggesting little "rebound effect" induced by cheaper natural gas prices. Furthermore, prospects for some coal-fired power stations are weakened further by Mercury and Air Toxics Standards (MATS) which will take effect in April 2015. The EIA (2012) projects that this will lead to significant retirement of coal-fired power capacity. These trends are likely to reduce externalities significantly. Detailed county-level modelling for the United States suggests that by taking into account estimates of the environmental and health impact of coal-fired power generation the harmful impact of air pollution from the sector is double the conventional measure of value added. By contrast, the ratio of harmful impacts of air pollution from natural gas-fired generation to the sector's value added is only one third (Muller et al., 2011).

Natural gas can play a role in helping renewable energy gain a greater share of electricity generation by helping to address the intermittency problem. Renewables are often a "must-take" generation source, which means that when electricity generation from renewable sources fluctuates the system operator must somehow achieve balance elsewhere (Weiss et al., 2013). From a security-of-supply perspective renewables can thus create challenges to system operators. As natural gas fired generators can adapt relatively quickly to changes in demand and supply they have a role to play in facilitating the expansion of renewables. This might happen because electricity production from natural gas would help meet demand when generation from wind and solar electricity drops or rises due to changes in wind and sunlight. In this context, an energy mix focusing on the combination of natural gas and renewables in electricity generation will go a long way towards providing reliable supply while lowering US greenhouse gas emissions. However, gas-powered generators cannot react quickly enough to offset sudden large surges or drop offs in renewable supply. In this context, developing storage capacity, smart grid technologies and price sensitive demand would complement renewable and natural gas generated electricity (Benatia et al., 2013).

Finally, relatively low natural gas prices will also affect emissions from the transport sector, making natural gas powered vehicles more attractive. Already low natural gas prices and the expectation that they will remain low has induced investment in natural gas powered vehicles. The implementation in 2014 of EPA regulations extending fuel economy standards to medium and heavy-duty vehicles will likely give a further fillip to natural gas powered vehicles. As the refuelling network is expanded this could induce an expansion from short-haul to long-haul trucking, leading to further gains in emission reductions (EIA, 2013). The EIA projects that the transportation sector's consumption of natural gas will almost double by 2040, with a large part of demand driven by gas-powered heavy duty vehicles.

The shale gas challenge for climate change

Fugitive methane emissions and gas flaring

While the substitution of natural gas for coal leads to lower emissions in electricity generation, the production of non-conventional natural gas leads to emissions of fugitive methane during production, due to leaks from loose fitting pipes and venting from gas wells, and transportation. More work remains to be done to quantify the scale of these emissions and at what points in production and transportation they occur. More is known about production than distribution (Allen et al., 2013; EPA, 2013; IEA, 2012). Accounting for these emissions could significantly reduce the climate benefits from switching to natural gas, though they are unlikely to offset the long-term benefits from substituting away from coal. Furthermore, relatively few sources may be high emitters and tools to identify rapidly and fix these leaks could have large benefits (Brandt et al., 2014).

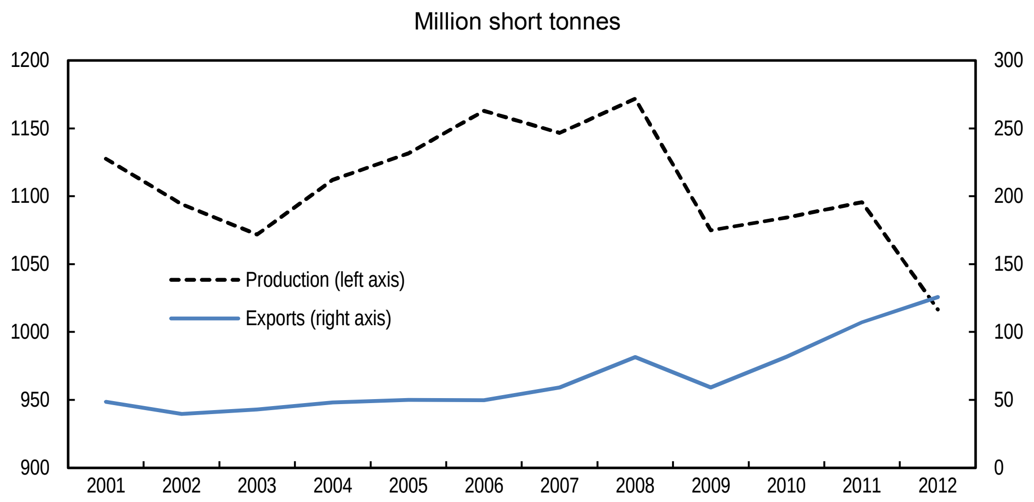
The EPA has in place a long-standing and voluntary Natural GasSTAR Programme that encourages the use of cost-efficient technologies to reduce and capture methane emissions. The administration has announced a strategy to reduce methane emissions from the oil and gas sector, building on the STAR programme. EPA guidance was to flare these emissions, as this reduces the potency of the emissions, but following amendments to air regulations for the oil and gas industry in 2012 (new source performance standards) companies are encouraged to move towards "green completion" of wells, which separates gas and liquids flowing from the well and captures the gas. The second phase of the amendments starting in

2015 requires companies to capture the gas and make it available for use or sale. In some cases, states and local governments have already moved to address this issue for example, Colorado, in collaboration with industry, has established regulations on minimising methane emissions. In other cases, states have considered using taxation on flaring or venting, which would help gas producers internalise global externalities. The differences across states regarding regulations on flaring or venting methane can be considerable, partly reflecting the relative development of pipeline infrastructure. For example, flaring methane in Texas is permitted in some case for 180 days, whereas in North Dakota flaring is allowed for one year before becoming liable to pay taxes and royalties on the flared gas. In addition, exemptions may then be granted if there are difficulties in connecting to a pipeline. At times, almost one-third of all gas produced in North Dakota has been flared or otherwise not marketed (EIA, 2011).

Knock on effects on energy markets

The substitution of natural gas for coal has seen repercussions on the market for coal. Despite declining domestic demand, US coal production has fallen relatively little as coal exports have more than doubled since the shale gas boom began to take hold in 2007 (Figure 10). Low carbon permit prices on the European market are inducing energy producers to increase their combustion of coal leading to a global rise in carbon emissions. Appropriately pricing the carbon content of fuels, such as with an emission tax, both in the United States and other countries, would ensure that the environmental benefits of switching to natural gas in one country are not lost through increasing coal consumption in other countries (see Golosov et al, 2014). Further rapid increases in coal exports may be limited by capacity constraints at existing export terminals coupled with local opposition - concerned about particulate matter pollution - to increasing railroad transportation and constructing new coal yards at ports.

Figure 10. **Coal production has fallen while exports have risen**



Source: Energy Information Administration.

Risks of lock-in

A final challenge for climate change policy arises from the risk of lock in, whereby choices made today will limit the opportunities available in the future. The development of shale gas can support the transition towards a lower carbon economy. As seen above, relatively low natural gas prices have already encouraged fuel substitution towards less carbon-intensive energy production and provide a platform on which to build. The question is will natural gas act as a “bridge fuel” to moving towards a zero net emissions target or lead to inertia to additional mitigation, which may also arise due to stranded assets. In the absence of concerted action to manage the transition there is a danger that as relative prices change or in the longer-term as natural gas begins to be depleted the energy market will respond by switching back to coal-fired power. In this context, while the shale gas boom could provide the "bridge fuel" towards a lower carbon economy, flanking measures (emission pricing, subsidising innovation, supporting renewables and developing smart electricity grids) will be required to ensure this outcome. In particular, two areas were flanking measures may be required are in countering natural gas hindering renewables and low prices stymieing innovation.

The expansion of natural gas fired generation may hinder the future development of renewable energy. The development of smart grids - which offers the potential to harness renewable energy effectively - is incremental and path dependent (Koenigs et al. 2013). Without careful preparation, the current expansion of natural gas and development of the supporting electricity infrastructure could hinder future movement towards a lower carbon economy by creating difficulties in integrating a larger share of more volatile renewable sources of energy. Against this background, the different government and private actors need to co-ordinate their activities and support long-term investments that will re-orientate transmission and distribution towards networks which can accommodate a larger share of low or (net) no carbon electricity generation. The US Energy Independence and Security Act (2007) and the American Recovery and Reinvestment Act (2009) have provided government support and funding for nationwide modernisation of the electrical grid and ensure stable mid-term prospects for private investors. The Federal Energy Regulatory Commission also works to promote the modernisation of the grid and the integration of renewables in electricity generation. Such actions are important in overcoming possible lock in effects.

Box 4. **The Regional Greenhouse Gas Initiative**

In 2009, the Regional Greenhouse Gas Initiative (RGGI), bringing together initially 10 states, introduced a cap-and-trade program for carbon dioxide emissions.[1] The initiative covers all large fossil-fuel electricity plants in the states with the cap based on long-term modelling predating the dramatic changes in energy prices, resulting in an initial allocation of too many allowances. The substitution towards natural gas has been particularly pronounced in the states covered by RGGI, with coal and oil-fired electricity generation falling from accounting for 35% of electricity production in 2005 to 13% in 2012. Furthermore, clement weather conditions reducing energy demand also helped bring down emissions dramatically below the agreed cap. In response, 9 of the original 10 states agreed to a 45% reduction in the cap from 2014.In addition, the cap is now designed to tighten further gradually. This feature should mean the emission cap becomes more challenging over time and that the price of emission allowances begins to rise. The states use revenues from the auction of allowances to support renewable energy and energy efficiency programmes.

To some extent the approach to climate change adopted by the administration, which has the effect of making coal-fired electricity generation less competitive, benefits schemes like RGGI by levelling the playing field and reducing possible concerns about "leakage". Nonetheless, combining command and control approaches with market mechanisms risks increasing the overall costs of climate change mitigation.

1. California subsequently introduced a cap-and-trade program in 2012.

At the state level, Renewable Portfolio Standards, in place in 30 states, will ensure that renewable sources account for a set share of generation. Under these programmes, electricity providers are mandated to purchase a specified share of electricity from renewable generation sources, usually with the share rising over time. While these policies have had a strong effect on the growth of this sector, and they may counter the danger of lock in, they nonetheless come at a higher cost than market-based mechanisms. However, removing restrictions in state Renewable Portfolio Standards on the location of renewable generation and mitigating federal and state incentives to generate power when prices are negative would increase the social benefit of these programs. (Schmalensee, 2013). Well-targeted and time-limited policies to support renewable energy can speed the deployment of renewable energy generation capacity.

A final area where low natural gas prices may present a challenge to greenhouse gas mitigation is through the effect on innovation. The United States is a leader in innovation on energy efficiency technologies, although only a fraction of government R&D support is allocated to the environment and energy (about 1.8% of government R&D). Patent filings related to green growth have been steadily rising since 1990 and began outpacing the growth of total US patents since 2005.The impressive gains in energy efficiency witnessed over the past decades were partly driven by high prices driving innovation in energy-saving technology (Popp, 2002; Aghion et al. 2012). In order to mitigate these undesirable outcomes, some subsidisation of innovation in energy saving technology to “direct” technical change would be warranted. Such an approach would be in line with the policy mix advocated by Acemoglu *et al*. (2012), who showed that optimal environmental policy would use carbon taxes in combination with subsidies to direct innovation activity towards the “clean” sector when goods are substitutable. Case study evidence supports an approach of combining taxation and subsidisation in promoting innovation to improve environmental outcomes (OECD, 2010). At the federal level, the America COMPETES Act created the Advanced Research Projects Agency - Energy, which funds energy technology projects. More recently, the administration has proposed to create an Energy Security Trust Fund, which would work in this direction. Certain states, notably California - and also participants in RGGI - have also invested in promoting energy efficiency and clean generation technologies.

Recommendations

Hydraulic fracturing

- Study the environmental impacts of hydraulic fracturing and develop regulations to address any negative impacts including, if necessary, legislative action to harmonise regulation across states and strengthen *ex ante* environmental impact assessments for drilling projects.
- Invest in skills and infrastructure using receipts from profit taxes levied on oil and gas production.

Climate change

- Further lower emissions with efficient policy tools as part of the climate-change strategy, notably by putting a price on greenhouse gas emissions, though well-designed regulation and investment in renewables also have a role to play.
- Promote innovation in energy saving and low carbon technology.

Further recommendations

- Ensure that trade restrictions do not hamper energy exports.
- Study the problem of fugitive methane emissions, and develop regulations to address any negative impacts.
- Promote investment in infrastructure for energy transportation, taking into account safety concerns.

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ANNEX

OIL AND GAS RESERVE DEVELOPMENTS

Introduction

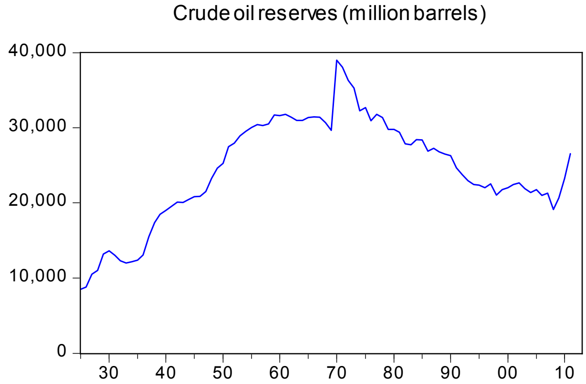
1. The successful deployment of hydraulic fracturing technologies is contributing to an energy renaissance in the United States. Natural gas supply in particular has surged and estimates of potentially recoverable natural gas resources have been revised upwards considerably. Developments for crude oil have been similar if less spectacular. Against this background, how policy can affect the development of natural gas and crude oil deposits acquires some importance. The form of taxation most typically used in the United States is the severance tax, more commonly known as a royalty tax. This form of taxation has adverse effects on the incentives to developed new reserves and also to abandon wells earlier than they would be using other forms of taxation, such as profit taxes, which are neutral to development and production.

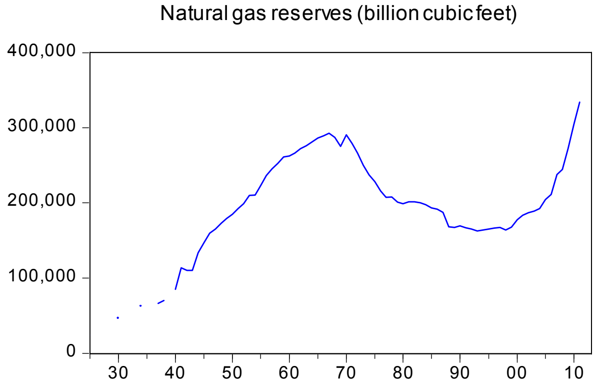
2. The analysis in this annex examines the impact of taxation on the addition to natural gas and crude oil reserves using US state-level data. This annex contains, first, a description of recent developments in natural gas and crude oil reserves. It then briefly examines determinants of oil and gas reserve growth. The third section describes the available data and the empirical approach to assessing these influences. This is followed by a presentation and brief discussion of the results.

Recent reserve developments

3. Estimates of proved reserves of oil and gas have altered dramatically recently, following the successful deployment of new technologies for advanced drilling. The Energy Information Agency markedly increased its estimates of recoverable gas resources (Figure 1). The addition of new proved reserves has maintained the ratio of reserves to production for crude oil, which has been relatively stable over a prolonged period. The recent surge in natural gas proved reserves has reversed a prolonged decline in the reserves to production ration over the second half of the 20th century (Figure 2).The distribution of shale gas deposits across the country is quite widespread, though the proved reserves are predominantly located in a handful of states, which is also where the large shale gas plays (i.e. where production is occurring) are located. These developments have seen the proved natural gas reserves increase significantly in a number of states (Figure 3). Recent increases in crude oil reserves have been relatively less substantial overall, but within a handful of states (notably Texas, North Dakota) the increases in proved reserves of oil is dramatic.

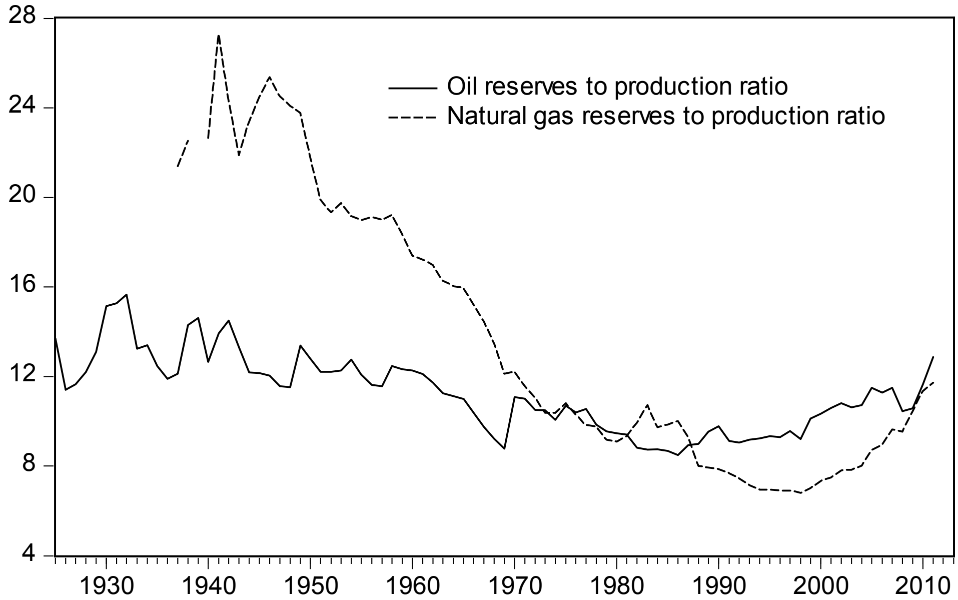
Figure A.1. Oil and natural gas proved reserves





Source: Energy Information Agency

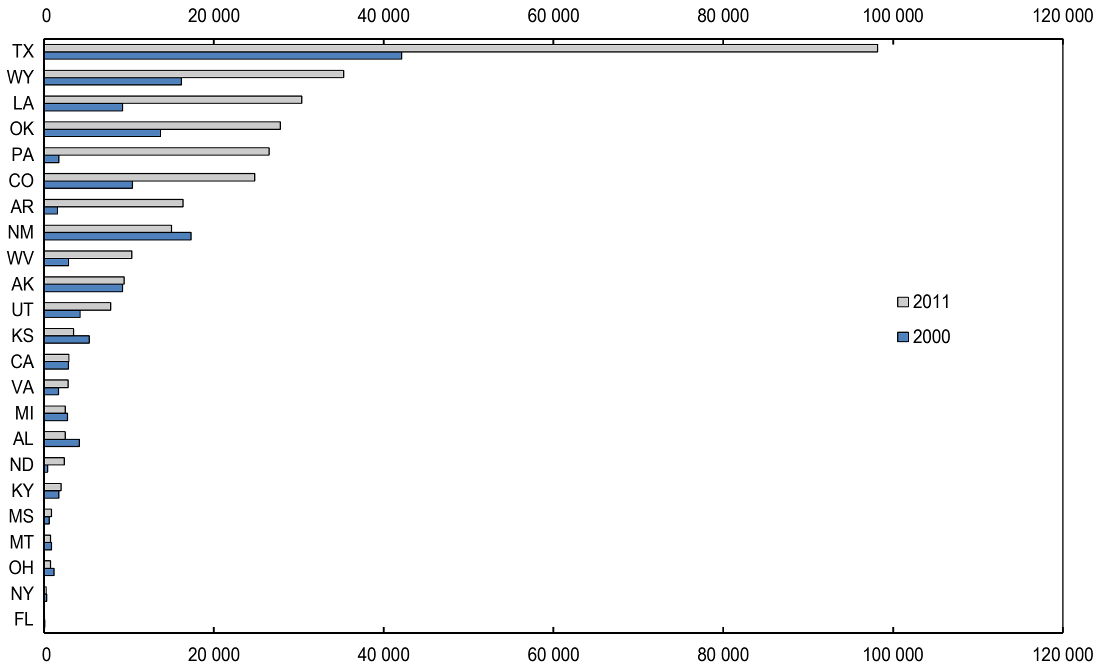
Figure A.2. Reserves to production ratios



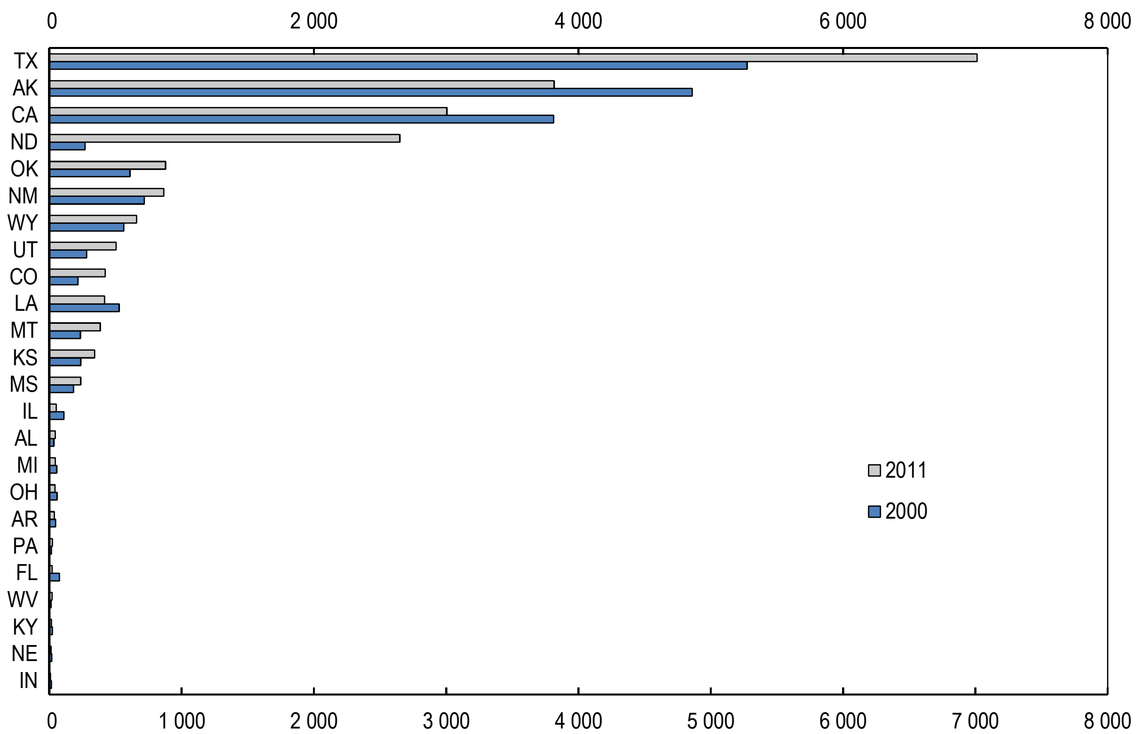
Source: Energy Information Agency

Figure A.3. Distribution of natural gas and oil reserves across states

Panel A. Natural gas reserves (billion cubic feet)



Panel B. Crude oil reserves (million barrels)



Source: EIA

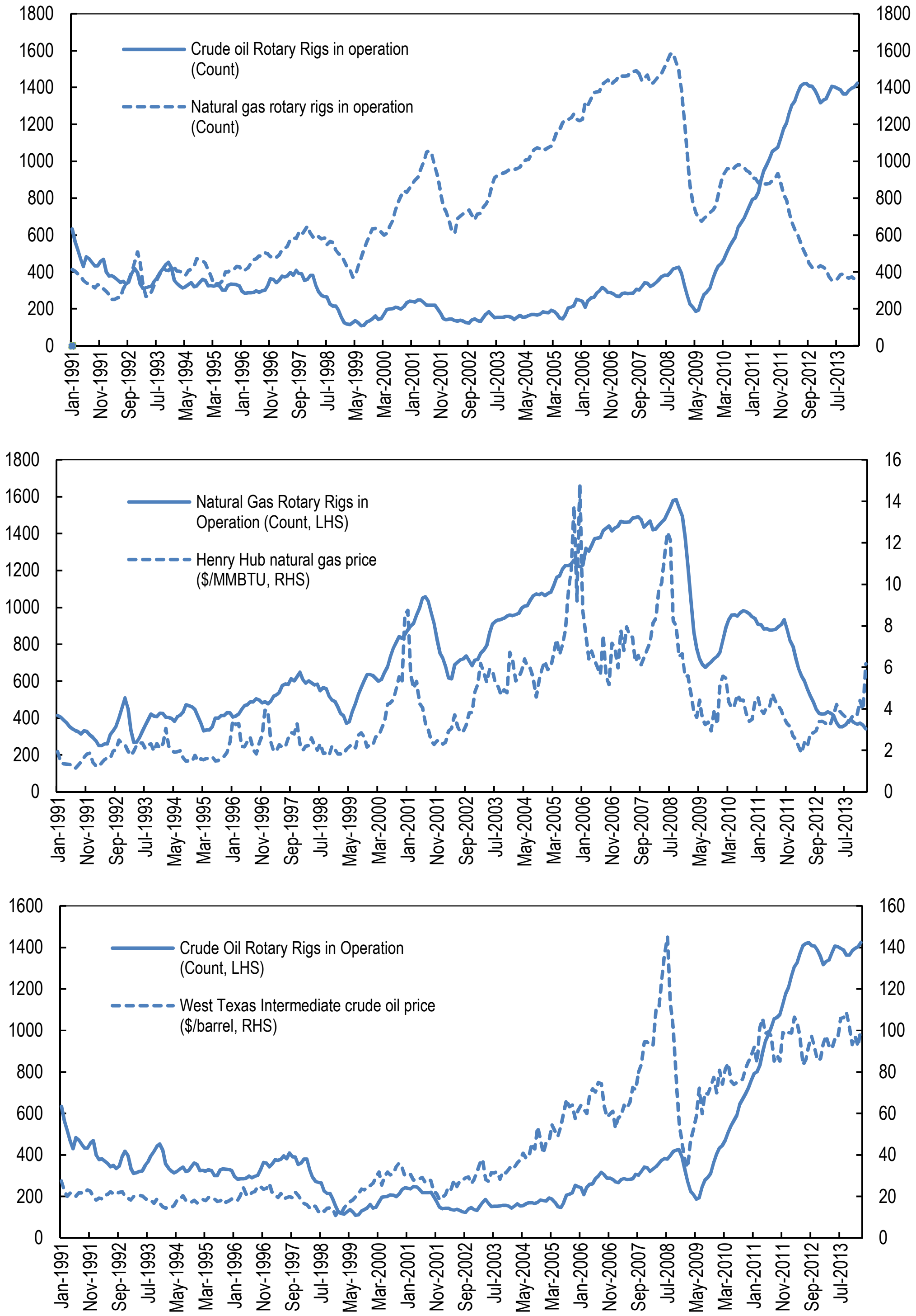
Factors affecting reserve developments

4. Examining reserve development rather than supply can avoid some of the complications presented by the effects of changes to the rate of extraction and the influence of storage on short-run supply (Ponce and Neumann, 2014). The approach adopted here looks at factors influencing the development of proved reserves (IEA, 2013). Energy prices will play a role in determining proved reserves by affecting the share of already discovered technically feasible reserves that are recoverable given extraction and other costs. Prices will also affect the date at which a well is abandoned: other things being equal, rising prices are likely to keep a well in production longer.

5. Empirical findings suggest that natural gas supply is inelastic in the very short run, but is more elastic in the longer run (Ponce and Neumann, 2014). While supply may be relatively inelastic, investment in exploration and development appears to react to price changes, as shown by the rapid increase in the number of crude oil rotary rigs when relative prices changed for oil and gas (Figure 4). In 2007/8 as the shale gas boom began to lead to a surge in supply, natural gas prices collapsed while crude oil prices continued recovering after the financial crisis, pushing up the relative price of crude oil substantially. Other factors may also lead to a structural break in the oil and gas mining sector around this time. The successful introduction of hydraulic fracturing may have affected the success of finding reserves. Forbes and Zampelli (2002) argue that deposits in tight sands and shale are easier to locate than conventional reserves and that hydrocarbons at shallower depths are more easily discovered.

6. Besides the physical availability of drilling rigs, the tax regime in place is likely to influence incentives for exploration and development of reserves. Andrade de Sá and Daubanes (2014) point out that royalty taxes are likely to blunt incentives to develop reserves and also give incentives to abandon wells before would be the case with other taxes, such as profit taxes. Royalty (severance) taxes are the predominant tax instrument used in the United States for capturing some of the resource rent. Only Alaska implements a profits tax (alongside a royalty tax). On the other hand, Pennsylvania does not attempt to tax the resource rent from hydraulic fracturing. Taxes on production reported by the BEA for the oil and gas mining sector includes severance taxes and also the normal corporate income taxes, which the federal authorities levy on all companies. The overall tax take relative to sectoral value added can vary enormously across the states, but also across time within states (Figure 5). To some extent these differences will reflect the differences in the severance taxes, though variations in tax schedules, such as lower rates offered for the use of enhanced recovery techniques, will also play a role. The Census Bureau reports state severance tax revenues. However, these revenues are not restricted to oil and gas mining.

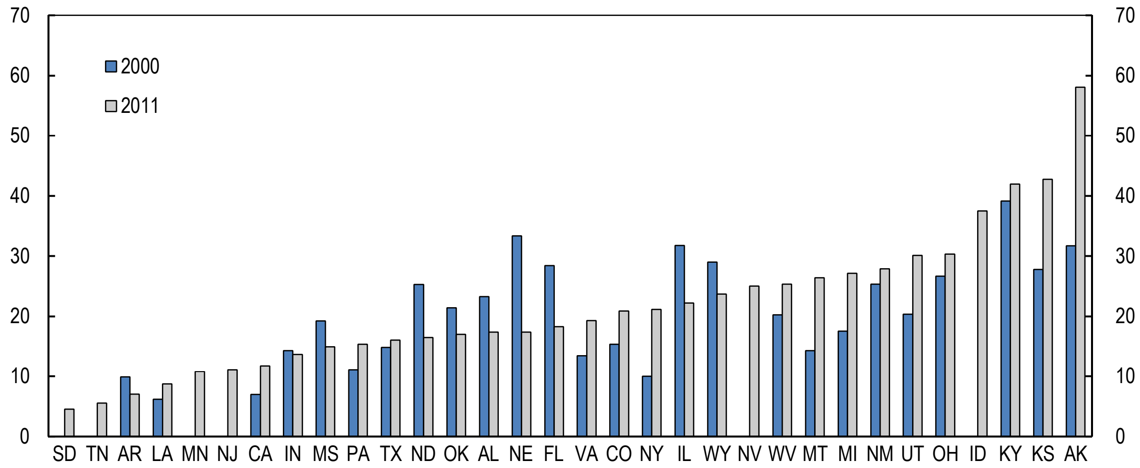
Figure A.4. Exploration activity and price developments



Source: Baker Hughes, Datastream

Figure A.5. Production taxes on oil and gas mining

As % of sectoral value added



Source: BEA

Estimation and data

7. The empirical approach adopted is an autoregressive distributed lag (ADRL) model (Pesaran *et al*., 2001). This approach allows the estimation of a relationship in levels as well as complex short-run dynamics and the mixing of series that are stationary and non-stationary. The general form of this model is:

$$Y_t = \mu + \sum_{k=1}^{p} \rho_k Y_{t-k} + \sum_{j=1}^{q} \beta_j X_{t-j} + \varepsilon_t$$

where Y is the dependent variable and X is a set of explanatory variables. The actual specification used in the following analysis exploits the state-level information using a panel data approach, taking the form of an unrestricted error correction model with the following specification:

$$\Delta Y_{i,t} = \mu + \sum_{k=1}^{p} \rho_k Y_{i,t-k} + \sum_{j=1}^{q} \beta_j X_{i,t-j} + \sum_{m=1}^{r} \mu_i \Delta Y_{i,t-m} + \sum_{n=1}^{s} \theta_l \Delta X_{i,t-n} + \mu_i + \varepsilon_{it}$$

where Y is the measure of reserves (dry and wet natural gas reserves and crude oil proved reserves) and X includes the relevant natural gas or crude oil price, the number of drilling rigs operating in the state and the tax revenues in the oil and gas mining sector. The model is estimated with state-level fixed effects to take into account unobserved heterogeneity at the state level. As energy prices are not available at the state-level, period fixed effects are not used. The lag length is set to one, partly due to the limited number of time periods available, but this choice is also supported by the Schwarz criterion for lag length selection.

8. The addition to reserves is assumed to be driven by energy prices, the exploration and development activities and the prevailing tax regime. The data for reserves is taken from the Energy Information Agency (EIA) using proved dry natural gas reserves (wet reserves are also used for robustness checks) and crude oil for states. Drilling activity at the state level is from Backer Hughes, but this has the shortcoming that state level information does not indicate whether the drilling rig is being used for oil or natural gas exploration. Information on taxes on production and value added in the sector are from the

Bureau of Economic Analysis, while information on severance taxes is from the Census Bureau. Price data were taken from Datastream, including the natural gas wellhead price and Henry Hub indices for gas prices and the West Texas Intermediate index for oil prices. Data availability and general characteristics of the data are given in Table 1. The time series properties of the data in logs are given in Table 2, revealing that none of the series used in the analysis are I(2), which is a requirement for using the ARDL approach.

Table A.1. Data characteristics

	Mean	Median	Standard deviation	Observations	Period
State Data					
Crude oil reserves (% change)	0.8	-1.0	20	798	1978-2011
Dry natural gas reserves (% change)	5.8	1.5	40	745	1978-2011
Wet gas reserves (% change)	5.7	1.4	40	705	1980-2011
Shale gas reserves (% change)	601.0	35.8	2232	44	2008-2011
Production tax as % of value added	15.8	15.1	13	602	1997-2011
Number of rigs	30.8	5.0	89	999	1987-2013
National data					
Henry Hub natural gas price	9.4	6.6	31	24	1990-2013
Natural gas wellhead price	7.9	4.9	29	37	1976-2012
West Texas Intermediate crude oil price	10.6	-0.2	30	28	1986-2013

Source: EIA, BEA, Census Bureau, Datastream.

Table A.2. Time series properties

Unit root tests for sample 1997-2013

	level		First differences	
	IPS	LLC	IPS	LLC
Oil reserves	1.06	1.35	-14.50 ***	-15.90 ***
Gas reserves	5.08	3.21	-7.35 ***	-9.24 ***
Drilling rigs	-1.44 *	-2.14 *	-11.67 ***	-16.00 ***
Taxes	3.99	1.33	-11.69 ***	-15.08 ***
	ADF		ADF	
Oil prices	-0.05		-6.17 ***	
Natural gas wellhead price	-1.82		-4.25 ***	
Henry Hub natural gas price	-1.94		-4.63 ***	

Note: IPS stands for the Im, Pesaran and Shin W-stat, LLC stands for the Levin, Lin and Chu test, and ADF stands for the Augmented Dickey Fuller Statistic

Results

9. The estimations examine the relationship between reserves and prices, drilling rigs and various measures of taxation in reduced form equations. The first set of estimations is for the period up until the shale gas boom was beginning to have a marked effect on supply (1998-2009). The results reported in Table 3 show that the estimates for the long-run relationship in the first column have the expected signs and are statistically significant. The implied long-run elasticity of around 0.5 for natural gas prices is similar to findings for the price elasticity of natural gas supply using monthly data (Ponce and Neumann,

2014). Investment in the number of drilling rigs is unsurprisingly associated with reserve growth. Higher tax revenues from the oil and gas mining sector slow the development of natural gas reserves. The estimates using slightly different measures of reserves and prices are very similar (Column 2 uses wet natural gas reserves, while Column 3 reports results when using the Henry Hub natural gas price rather than the wellhead price). When the sample is extended to 2011, the statistical significance diminishes, though the estimates are quantitatively similar in size. In part, this result is driven by the inclusion of Pennsylvania, where exceptionally rapid reserve growth in 2010 and 2011 suggest that a structural break occurs when the hydraulic fracturing boom takes hold. Finally, the results reported for crude oil reserves are weak, with most variables being statistically insignificant. Dropping the tax variable, so as to estimate the equation for a longer time period reveals the expected long-run relationship between reserve and prices as well as investment in drilling rigs. The implied long-run elasticity of supply of almost 0.4 is close to other estimates (Brook *et al*, 2004).

Table A.3. Estimation results

	Natural gas 1999-2009	Natural gas[1] 1999-2009	Natural gas[2] 1999-2009	Natural gas 1999-2011	Crude oil 1999-2011	Crude oil 1989-2011
Lagged level						
Reserves	-0.18 **	-0.17 **	-0.18 **	-0.04	-0.15 *	-0.10 **
	0.08	0.08	0.08	0.04	0.08	0.05
Price	0.13 ***	0.13 ***	0.13 ***	0.04	-0.02	0.04 **
	0.05	0.05	0.05	0.03	0.04	0.02
Rigs	0.13 ***	0.14 ***	0.14 ***	0.09 ***	0.05 *	0.03 *
	0.04	0.04	0.04	0.03	0.03	0.02
Tax	-0.13 **	-0.13 **	-0.12 **	-0.05	0.04	
	0.06	0.06	0.06	0.03	0.04	
Lagged first differnce						
Reserves	0.12	0.12	0.15	0.18	-0.11	-0.12 *
	0.12	0.13	0.12	0.11	0.08	0.06
Price	-0.09 **	-0.09 **	-0.09	-0.06 **	-0.07	-0.08 **
	0.04	0.04	0.06	0.03	0.05	0.04
Rigs	-0.04	-0.04	-0.05 *	0.00	-0.02	0.00
	0.03	0.03	0.03	0.02	0.03	0.02
Tax	0.05	0.05	0.03	0.00	-0.02	
	0.06	0.06	0.06	0.05	0.06	
Constant	1.56 **	1.54 **	1.52	0.32	0.58	0.31
	0.59	0.61	0.58	0.30	0.44	0.03
Adjusted- R^2	0.20	0.20	0.19	0.23	0.09	0.08
State fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Cross-sections	23	23	23	23	24	24
Period	11	11	11	13	13	23
Observations	244	244	244	286	264	483

Note: Robust standard errors are reported, * p<0.1, ** p<0.05, *** p<0.01

1. Wet natural gas proved reserves are used in place of dry natural gas proved reserves

2. Henry Hub natural gas price is used instead of the wellhead price

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