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# The US shale gas revolution: An opportunity for the US manufacturing sector?

Yassine Kirat\*

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## Abstract

This paper provides new empirical evidence on the impact of the shale gas revolution on manufacturing output and trade in the United States. The shale gas boom has led to significant and persistent regional price differences in natural gas between the United States and the rest of the world. The results show that lower natural gas prices in the United States compared to Europe have led to industrial activity and investment increasing by nearly 3% and 2%, respectively. We provide empirical evidence also of structural breaks in the relationship between natural gas prices and both imports and exports. Finally, we suggest that while the shale gas revolution has helped some industries to expand, its impact on the manufacturing sector as a whole has been relatively weak.

*Keywords:* Manufacturing, shale gas, energy prices, growth, dynamic panel data.

*JEL codes:* C23 - Q43

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## 1 Introduction

In the 21st century energy supply continues to be a major issue. Fossil fuels are the major source of energy and are forecast to satisfy 87 percent of energy needs up to 2025. However, natural gas is the only source of energy for which global demand is forecast to grow in all scenarios (Energy Information Administration, 2015). Natural gas would appear to an alternative to other energy sources due to its abundance and lower polluting capacity (Hu and Xu, 2013; Maya, 2013). In the US, from 2000 onwards, the production of natural gas decreased slowly despite the rise in the drilling activity. The falling supply led to higher prices in the US market, which was met by a drive to import liquefied natural gas (LNG) from Trinidad and Tobago (Energy Information Administration, 2007). Meanwhile, shale gas operations developed gradually, and represented only 1% of the total natural gas production in the US in 2000. At the time, there was no hope that changes in unconventional natural gas production could bring opportunities for enhancing security of supply in the US market. However, unexpected technical advances associated with two existing extraction techniques – horizontal drilling and hydraulic fracturing – have allowed the massive extraction of shale gas to emerge as a resource, from 2006 onwards. This development has offset the depletion of conventional natural gas. In 2013, shale gas represented about 40% of the total natural gas production in the US (Energy Information Administration, 2015). This positive supply shock lead North America to be ranked as the second region with the lowest costs for energy and raw materials in the world, after the Middle East (Cornot-Gandolphe, 2013). This achievement of the US has caused heated debate about shale gas worldwide, particularly in Europe. The supporters of shale gas highlight the outlook for economic growth and reduction in energy imports dependency. Opponents point to the clear danger for the environment due to the hydraulic fracturing process (Vengosh et al., 2014; Rahm et al., 2013). In this context, the present study aims to contribute to this debate by identifying and assessing the impact of massive shale gas development on the US manufacturing sector.

Despite controversy and a lack of definitive answers on its likely negative impact on environment, the expansion of the gas industry has undeniably provided a windfall to the US economy in multiple dimensions (Kinnaman, 2011). Indeed, three effects are observable: a direct effect, an indirect one and a competitiveness effect. The direct effect captures changes in the economic activities of oil and gas extractive industries, as employment increases in mining areas. The indirect effect relates to upstream sectors of the industry, such as suppliers who take advantage of increased demand due to investments in oil and gas extractive industries. Finally, the downstream effect corresponds to changes in economic activity in industrial sectors that benefit from lower prices of energy input (natural gas in this case). Natural gas price decreased by 70 percent from

2008 to 2012 (Energy Information Administration, 2015). Indeed, the fall in natural gas price has enabled companies to reduce their costs of production, which increases the competitiveness of manufacturing sectors, especially those that are the most energy-intensive.

The boom in the production of oil and natural gas in the United States has generated a plethora of comments and analysis. A large majority of these studies are purely descriptive for the impact at the macro level. Nevertheless, some authors have tried to quantify the economic impact of this boom.

A first strand of the literature analyses the impact of shale gas exploitation on the US economy using a computable general equilibrium model. Houser and Mohan (2013) conducted an in-depth analysis to compute the new production costs for US manufacturing industries, considering the decline of oil and natural gas prices through to 2035. Between 2013 and 2020, they estimate that the oil and gas boom could lead to a cumulative 2.1 percent increase in economic output. Based on these low costs effects, they argue that relatively few industries will benefit from a substantial competitive advantage. Morse et al. (2012) provide an initial impact to quantify the downstream outcomes of the shale gas boom. This boom will lead to an increase of 1.1 million jobs in manufacturing by 2020, a 9 percent increase compared to the scenario without the energy boom. They also find that the real GDP grows by 0.2 percent above baseline by 2020. This implies a 1.6 percent increase in manufacturing production, which accounted for 12.5 percent of GDP in 2012. The overall effect seems relatively low.

General equilibrium models are based on assumptions of general equilibrium of all markets, in order to study the impact of shale gas by using the parameter calibration technique (based on past periods). Drawing on a different approach, this paper uses real data to estimate the effect of the shale development and contributes thus to the second strand of literature on empirical models of trade flows and trade policy.

Celasun et al. (2014) use the cross-country panel data to estimate the response of the manufacturing sector's output, considering changes in relative natural gas prices (domestic vs. world average) for the period 2001-2013. According to their results, if the natural gas price differential is multiplied by 2 in favor of the home country, manufacturing industrial production will increase by 1.5 percent. Sendich (2014) explores the direction of causality between gas prices and manufacturing output to see whether gas prices are a determinant of production. She uses Granger causality tests and focuses on 12 energy-intensive manufacturing industries in the US. She concludes that for 8 of the 12 industries, there is a significant link between natural gas prices and production, confirming the potential importance of the downstream effect. Arezki et al. (2017) investigate the response of US manufacturers to changes in production and trade brought about by the decrease in the price of US natural gas. Various measures of manufacturing activity are investigated, using a panel data model of 158 US industries trading with 218 countries and territories. The results show

that the fall in US gas prices since 2006 has been associated with a 10 percent increase in exports for the whole US manufacturing sector. They find no impact on imports and claim that the US shale revolution is operating both at the intensive and extensive margins.

To sum up, few quantitative studies have figured out a positive but relatively small impact on the competitiveness of the US manufacturing industry as a whole, except for the effects on employment pointed out by Morse et al. (2012) and on exports by Arezki et al. (2017).

This study considers the manufacturing sector as defined in the North American Industry Classification System (NAICS).<sup>1</sup> It aims to address the impact of shale gas revolution on the US manufacturing sector. To do so, it assesses the impact on several macroeconomic variables of the price difference of natural gas between the US and Europe, using annual data for a group of 79 industries over the period 1997-2013. First we build an "energy-intensity" variable, from the MECS (Manufacturing Energy Consumption Survey) conducted in 2006, which gives a precise indication of the industries that are more likely to take advantage from the drop in gas prices. This variable gives information on natural gas and energy consumption levels close to the date of the positive supply shock that happen in the US gas market. We also test whether a structural break occurred in the relationships between five macroeconomic variables and natural gas prices after the sharp drop in natural gas price from 2006. We find evidence of structural breaks in the relationship with natural gas price only for imports and exports. We finally estimate a dynamic panel data model which allows to compute the short-term and long-term elasticities. The results show that the decline in natural gas price ratio of US over Europe has led to an increase in industrial activity and investment of nearly 3% and 2%, respectively, for the whole manufacturing sector. When we account for structural breaks, we find that exports increase by nearly 0,70% while imports decrease by nearly 0,90%. Regarding the sectoral impact, there is a significant variation in terms of results. Indeed, Industrial activity in the twenty most intensive sectors increased by 30% on average as a result of the fall in gas prices. Moreover, we find that even if some industries are expanding, this does not seem to have a significant effect on the whole manufacturing sector till now. These results should be interpreted with caution given that firms adjust their production processes only gradually. The total effect of this energy boom is maybe still to come and has not yet been realized.

The remainder of the paper is as follows. In section 2, we discuss the existing markets place of natural gas and their implications for gas prices. Section 3 describes the dataset and discusses the empirical strategy. Section 4 presents the main results. Section 5 concludes.

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<sup>1</sup>The North American Industry Classification System (NAICS) is the system of classification used by federal statistical agencies to categorize the products and services of business establishments in order to gather, analyze and provide statistical data on business activities in the United States economy.

## 2 The natural gas market and the economy

### 2.1 Specificity of the natural gas market

The international natural gas markets are not integrated like international oil markets (Li et al., 2014). They are segmented into three different geographical areas: North America, Europe and Asia. The prices set in natural gas markets are governed by different mechanisms. However, they mostly have similarities related to the intrinsic characteristics of natural gas which led to entry barriers. These barriers are related to high transport costs (by pipeline or methane tanker) and high transformation costs (liquefaction, regasification) necessary to allow the product to be marketed. Gas transportation generates the largest costs in the gas industry (Maxwell and Zhu, 2011). The specific constraint of this type of energy product stems from its gaseous state and its relatively low density. Indeed, one ton of gas represents the energy equivalent to 0.89 tons of oil, which is about the same order of magnitude. However, a ton of oil occupies a volume of  $0.85m^3$  while a ton of gas occupies a volume of  $1000m^3$ . Thus, the transport of the same amount of energy under standard condition of temperature and pressure is generally 4 to 6 times more expensive (Lochner and Bothe, 2009). Pipelines are the most frequently used method for the transportation of natural gas in world trade (about 80%). In order to be transported by pipeline, gas is compressed and maintained under pressure by compressors installed every 100 km or less, over distances up to 6,000 km. This compression allows the volume of gas to be reduced. Pipelines can be over land (North America and Russia), submarine or underwater (North Sea). The gas may also be transported by ships. To be efficiently transported by ships, natural gas must be transformed into a liquid state at a temperature of  $-160^\circ$ . Once stored as a liquid, its volume is 600 times smaller than in its gaseous state and can then be carried by refrigerated tanks to a regasification plant. These exorbitant transportation costs create significant regional gas price differentials, and provide a competitive advantage to the various economic players in the region which offers the lowest prices. It is the case of North America.

### 2.2 Trends in US gas market

In the early 2000s, the US oil and gas industries were concerned about the depletion of conventional natural gas reserves. Most experts believed that North America would become a net importer of LNG. The US Energy Information Administration (EIA), in its Annual Energy Outlook 1999, anticipated an increase of 12.9% to 15.5% of net imports of natural gas between 1997 and 2020. To face up to this situation, five new LNG import terminals were built in the second half of 2000s and other existing installations were brought

back into service, at increased capacity. However, against all economic forecasts, these facilities will not be of much use since shale gas is far more promising than expected. Starting from 2006, the gas industry realized that shale gas is an important and economically exploitable resource that could complement the depletion of conventional gas wells. Driven by high gas prices, over 32,000 exploration and development wells were drilled annually between 2006 and 2008. In 2010, proven reserves of natural gas and oil reached the highest levels recorded by EIA since 1977.<sup>2</sup> The United States became the largest producer of natural gas and oil ahead of Russia. This increase has been possible thanks to technological advances that have allowed exploitation of shale gas, which had not been available neither technically or economically before. In 2000, shale gas represented 1% of the US natural gas supply. The gas obtained from shale represents 75% of US gas production in 2020, and is experiencing constant growth. The large availability of domestic natural gas has led the US gas industry to change its objectives and strategies. One of them was the reorientation in the construction of LNG import terminals to become export terminals in the early 2010. More recently (January 2015), there were 48 applications for authorization to build liquefaction facilities to export gas in a liquefied form.

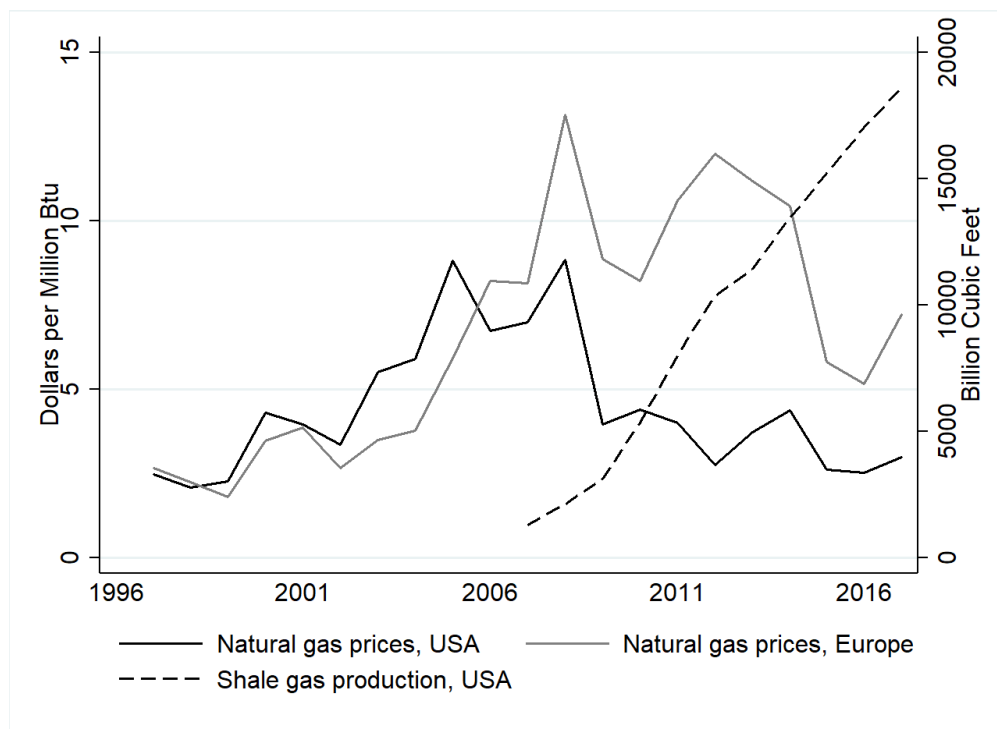


Figure 1: The evolution of natural gas prices and shale gas production.  
Source: U.S. energy information administration (EIA)

<sup>2</sup>Proven reserves of crude oil increased by 13 percent (2.9 billion barrels) and proven reserves of natural gas rose by 12 percent (33.8 trillion cubic feet). Oil reserves at the end of 2010 were 25.2 billion barrels and natural gas reserves at the end of 2010 were 317.6 trillion cubic feet– the first time they reached a level over 300 trillion cubic feet.

Figure 1 shows the increase in total US shale gas production from 2007 onward, as well as the change in the US natural gas price. The increase in shale extraction began in the late 2000s, accelerated in 2010, and amounted to more than 10000 billion cubic feet by late 2013. This strong increase in shale gas production has been stimulated by technological advances in horizontal drilling and hydraulic fracturing. As a result of this sustained growth in extraction, natural gas prices in the United States have fallen significantly, while not affecting European gas prices due to the regionalized nature of gas markets. This evolution has allowed the United States to become more competitive vis-à-vis Europe, where the gas price is still largely indexed on oil prices, and is three to four times as high as in the US. In 2012, the price of natural gas in Europe was on average 11.40 per MBtu, whereas it was only 2.75 per MBtu in the USA (11.10 and 3.45 respectively in August 2013). The price of imported gas in Europe was thus four times as high as US prices (compared to 2.7 times as high for 2009-2013). These trends have led to prices for European industry which are at least three times as high as prices for US industry. The picture is particularly problematic for energy-intensive industries facing international competition, such as chemicals, fertilizers and steel, etc.

In what follows, we assume that the differential between US and European natural gas prices captures the effect of the U.S. shale gas revolution. However, one may question whether variations in gas price difference are entirely due to the shale gas production. The answer is obviously negative and shale gas production cannot explain 100% of the change in the gas price ratio. Indeed, there are differences in the structure of gas markets in Europe and the US which prevent from getting the same gas price at each moment (Hulshof et al., 2016). However, the formation of gas prices on both markets reflects a common pattern: both are indexed to international crude oil prices.<sup>3</sup> We expect from price indexation theory that natural gas prices to be very similar in the US and Europe. Moreover, several studies have found long-run cointegration relationship between gas and oil prices (Asche et al., 2006; Regnard and Zakoian, 2011; Erdős, 2012; Villar and Joutz, 2006). However, since the US shale gas boom, US natural gas prices appear to have decoupled from those of international oil prices and inevitably from European gas prices. Indeed, since 2006, the US gas market become independent from that of European gas market. This is mostly due to the sharp increase in the US gas production induced by the shale gas boom occurred in the mid 2006 (Aruga, 2016).

Figure 2 illustrates the natural log of the natural gas price ratio of Europe over US with the total US proved reserve and production of natural gas. We observe that production and reserves are stable for the period before 2005. The price ratio fluctuates slightly, but remains stable. From 2006 onwards, we notice a significant increase in production, reserves, and in the price ratio. As discussed previously, the shale gas

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<sup>3</sup> As they are two potentially substitutable energy sources, relative gas and oil prices should reflect differences in their intrinsic calorific content in addition to production and transportation costs. The prices of these commodities must not deviate, or at least not persistently, from their fundamentals which leads to the hypothesis of oil price indexation.



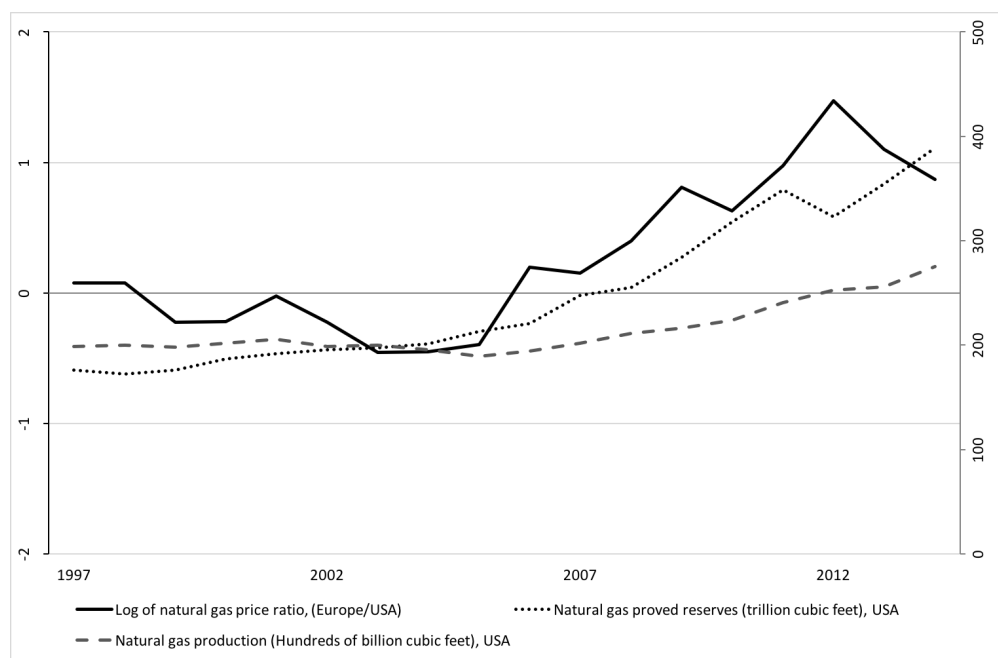


Figure 2: Natural gas proved reserve and production impacting natural gas price ratio.  
Source: U.S. energy information administration (EIA)

boom in the USA corresponds to this date. This is why we assume that the largest part of the change in the price ratio is due to the emergence of shale gas. To provide some additional evidence, we compute correlations between proved reserves, production and price ratio for the 2006-2013 period. The results are quite significant, since we get a correlation of 0.93 between log of price ratio and shale gas production, and a correlation of 0.95 between log of price ratio and natural gas proved reserve. This leads us to be quite confident about the quality of our proxy.

### 2.3 Rebirth of the US manufacturing sector

The unexpected expansion of the domestic energy supply gives an important economic advantage to US industry, which is leading some economists to talk about the US Manufacturing Renaissance (Bazilian et al., 2014). Indeed, industrial sector is one of the largest consumers of natural gas: it includes manufacturing, construction, agriculture and mining activities. It consumed 8.3 quadrillion ( $10^{15}$ ) Btu of natural gas in 2011, about one third of total US consumption.<sup>4</sup> For instance, the decline in natural gas prices has directly impacted US industry by lowering the costs of electricity production (Wang et al., 2014). During the last two decades, the use of natural gas in electricity generation has significantly increased from 11% in 1990 to

<sup>4</sup>One British Thermal Unit (Btu) is the heat that will raise the temperature of one pound of water by one degree Fahrenheit.

28% in 2012, mainly due to its substitution for coal. It is also a key component used in plastics, polymers, petrochemicals, steel, cement, and fertilizer production. In early 2013, the Boston Consulting Group (BCG) predicted that within five years, the United States would experience a rebirth of the manufacturing sector as companies relocated their manufacturing operations in USA. The report concluded that the benefits of production cost of goods manufactured abroad have dramatically fallen over the last decade. In 2003, manufacturing costs were 18% lower in China than in the US. In 2011, the difference was only of 7%. Natixis, a French corporate and investment bank, has confirmed that the competitive advantages accruing to US industrial manufacturers through lower gas prices are equivalent to a 17% reduction in wage levels compared to firms belonging to the Euro-zone. Cheaper energy also has the potential to create significant employment growth in both primary industries and secondary industries. Other actors see the development of natural gas as an opportunity to use less coal in electricity production and reduce dependence on oil through the liquefaction of gas in the transport sector. Gas producers, meanwhile, saw a great opportunity to benefit by exporting natural gas as LNG.

### 3 Data and empirical specification

#### 3.1 Economic intuition and variable of interest

Gas prices are used to estimate the shale gas impact because of the positive supply shock that occurred in 2006 in the US gas market, as a result of the massive exploitation of shale gas (Wakamatsu and Aruga, 2013; Caporin and Fontini, 2017). More specifically, the ratio of natural gas prices in the US and Europe. The German border price of natural gas in Europe is used as a proxy for average world prices. Two main reasons motivated our choice of the German border price. First, knowing that Europe and Asia are the major trade competitors of US manufacturing industries, and since a natural gas price gap between the US and Asia is larger than between US and Europe, only the European price is considered. This allows to compute the lower bound of the advantage provided to the US industries. Second, Russia and Norway are the two main suppliers of natural gas imported by Europe. They represent respectively 40% and 35% of imports in 2015 (BP Statistical Review 2015). They have a similar indexation, with prices pegged to over 80% on oil fuel products.<sup>5</sup> Consequently, gas purchased from these countries displays similar price levels. Indeed, given the fact that much of the Europe's current supply of gas comes from these two countries, it is natural to use Germany's eastern border price. The interest here using the spot price of National Balancing Point (UK NBP) would be limited due to the low representation and use of this gas in continental Europe especially as

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<sup>5</sup>According to the Energy Sector Inquiry from the European commission.

the UK became a net gas importer since 2005. In addition, by using co-integration analysis of import prices, Asche et al. (2002) found that the Belgium, German and French gas markets are integrated.

I also multiply the gas price ratio by the energy-intensity of each sector. It allows to construct a new proxy, which is more relevant. Indeed, this proxy provides a two-fold benefit. The first one is to obtain a measure of sectoral comparative advantages.<sup>6</sup> The second advantage is to create more variability in the data, which improves the efficiency of the used estimators.

### 3.2 Data description

This study aims to identify the response of the US manufacturing sector to the massive development of shale gas. The responses will vary with energy-intensity of each sector. To conduct the empirical study that takes advantage of variations in energy-intensities by sector, a variable needs to be used that measures this intensity. There are at least four measures of energy consumption allowing computation of the energy-intensity for each manufacturing sector; among them the Manufacturing Energy Consumption Survey (MECS) conducted every four years by the US Administration Energy Information (EIA).<sup>7</sup> MECS is a national sample survey that collects information on the stock of US manufacturing establishments, their energy related building characteristics, and their energy consumption and expenditures. The MECS 2006 sample size of approximately 15,500 plants was drawn from a nationally representative sample frame representing 97%-98% of the manufacturing payroll. The MECS measures energy consumed as fuel (such as for heating and lighting), and the energy consumed as a feedstock (such as naphtha used in the production of ethylene). Based only on energy consumption as fuel, MECS provides several measures of energy-intensity for different sectors. Among them, total fuel consumption in thousands of British thermal units (Btu) per dollar of value added and shipments. These two measures exclude the energy used as feedstock. However, a firm will take advantage of lower energy prices whether hydrocarbons are used as fuel or as feedstock. It is therefore important to have measures of energy-intensities that reflect energy use as fuel or feedstock. Thus, similar measures of energy-intensity are calculated, relating to the total energy consumption and total consumption of natural gas in two stages. The first stage aims to reconstruct measures of added value and shipments for each industry covered by the MECS, from the intensity and level data based on consumption as fuel. The second stage consists on dividing the total energy consumption and the total consumption of natural gas (Btu), including fuel and feedstock, by the added value and the shipments constructed in the first step. This provides four measures of energy-intensity by sector: a measure of energy-intensity of natural gas and

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<sup>6</sup>The gas price ratio distinguishes the advantage of the various sectors according to their energy intensities.

<sup>7</sup>Other measures of energy consumption are from Annual Survey of Manufactures (ASM), Bureau of Economic Analysis (BEA) using its KLEM (Capital, Labor, Energy, Materials) dataset and BEA's Input/Output data.

of total energy per dollar of value added and per dollar of shipments. Having two measures of calculation (natural gas and total energy) allows taking into account that energy-intensive industries (using oil, gas and coal) can substitute other energy sources to natural gas. The four measures are presented in Tables 6 in the Appendix.

The rest of the study focuses on the measures in thousands of Btu of total energy and natural gas consumption per dollar of added value and per dollar of shipment, from the survey MECS 2006. This choice reflects the convergence of the survey with the development of shale gas production in the US. These measures provide a better indication about which sectors should benefit more from lower gas prices, since they provide information on the levels of gas and the total energy consumption closer to the date of the positive supply shock in the US gas market.

Matching between measures of energy-intensity and different economic variables for each industry was achieved on the basis of the North American Industry Classification System (NAICS). The industrial sector in MECS 2006 database, however, does not necessarily have an exact match for each economic variable. Each organization involved in the production of these economic variables can cover a different set of manufacturing industries in addition to implementing the NAICS slightly differently. These variables are derived from different sources (see Table 7 in the Appendix).<sup>8</sup> Finally, 79 matches for the total energy-intensity and 78 for natural gas-intensity between the MECS 2006 database and other agencies were made, providing economic variables for each sector.

Five economic variables for each industrial sector are taken into account: industrial production, employment, capital expenditure, exports and imports. Variables are indicated for the period 1997-2013, except for capital expenditures that are only available until 2011, and employment until 2012. All these variables are in volume terms and transformed into logarithms, in order to interpret the results in terms of elasticity. The database also includes natural gas spot prices, using the Henry Hub prices in the United States, and eastern German border price in Europe (both taken from the International Monetary Fund). A balanced panel of 79 industrial sectors is obtained by identification of NAICS codes ranging from 3 to 6 digits, for the period 1997-2013.

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<sup>8</sup>Table 7 gives sources and units and shows the number of sectors that are matched with the MECS 2006 database.

### 3.3 Econometric model

#### Dynamic panel data estimator

To assess the relationship between various economic indicators and shale gas revolution in a panel, we use the generalized method of moments (GMM) estimators developed for dynamic panel models by (Arellano and Bond, 1991). We can write the regression as follows:

$$\ln(Z_{i,t}) = \beta_0 + \gamma \ln(Z_{i,t-1}) + \beta_1 \left[ \ln\left(\frac{NG_t^{USA}}{NG_t^{EUR}}\right) * I_{i,2006} \right] + \beta_2 \left[ \ln\left(\frac{NG_{t-1}^{USA}}{NG_{t-1}^{EUR}}\right) * I_{i,2006} \right] + \alpha_i + \nu_t + \epsilon_{i,t} \quad (1)$$

where the variable  $Z$  denotes alternatively industrial production, exports, imports, employment, and capital expenditure.  $\left(\frac{NG_t^{USA}}{NG_t^{EUR}}\right)$  is the natural gas price ratio of the US and Europe, and  $I_{i,2006}$  is the intensity of sector  $i$  in 2006. The unobserved sector-specific effect is  $\alpha_i$ ,  $\epsilon$  is the error term, and the subscripts  $i$  and  $t$  represent sector and time period, respectively. We also include time dummies  $\nu_t$  to account for time-specific effects. Estimation of equation (1) by classical estimators of panel data (OLS, Between, Within) is biased due to the presence of the lagged dependent variable among the regressors  $\ln(Z_{i,t-1})$ .<sup>9</sup> Table 12 in the Appendix shows the results for various estimators and highlights the biases associated with each of them.

The endogeneity issue is tackled by using the (Arellano and Bond, 1991) estimator.<sup>10</sup> The authors suggest differentiating the equation (1):

$$\ln(Z_{i,t} - Z_{i,t-1}) = \gamma \ln(Z_{i,t-1} - Z_{i,t-2}) + \beta_1 [\ln(X_t - X_{t-1}) * I_{i,2006}] + (\epsilon_{i,t} - \epsilon_{i,t-1}) \quad (2)$$

While differencing eliminates the sector-specific effect, it introduces a new bias; by construction the new error term,  $\epsilon_{i,t} - \epsilon_{i,t-1}$  is correlated with the lagged dependent variable,  $Z_{i,t-1} - Z_{i,t-2}$ . Under the assumptions that (a) the error term,  $\epsilon$ , is not serially correlated, and (b) the explanatory variables,  $X$ , are weakly exogenous (i.e., the explanatory variables are assumed to be uncorrelated with future realizations of the error term). Arellano and Bond (1991) suggest the following moment conditions.

$$E[Z_{i,t-s}(\epsilon_{i,t} - \epsilon_{i,t-1})] = 0 \text{ for } s \geq 2; t = 3, \dots, T, \quad (3)$$

$$E[X_{i,t-s}(\epsilon_{i,t} - \epsilon_{i,t-1})] = 0 \text{ for } s \geq 2; t = 3, \dots, T. \quad (4)$$

<sup>9</sup>In particular, the bias introduced by the within estimator is known as Nickell bias (Nickell, 1981)

<sup>10</sup>In the rest of this section, for simplification purposes, we will consider the model with a contemporaneous natural gas price ratio variable denoted  $X_t$ .

Using these moment conditions, they recommend a two-step GMM estimator. In the first step the error terms are assumed to be independent and homoskedastic across countries and over time. In the second step, the residuals obtained in the first step are used to construct a consistent estimate of the variance–covariance matrix, thus relaxing the assumptions of independence and homoskedasticity. The two-step estimator is thus asymptotically more efficient relative to the first-step estimator. We refer to the GMM estimator based on these conditions as the difference estimator.

There are, however, conceptual and statistical shortcomings with this difference estimator. It has been criticized for the weakness of the instruments induced by the use of instruments in levels for first difference variables. This is a valid statement when the lagged dependent variable are close to a random walk, which is not the case for our variable. The validity of the instruments can usually be tested through a Sargan test, assuming homoscedasticity disturbances. However, in the estimates here, the residuals’ variance-covariance matrix was corrected to account for heteroscedasticity, and once applying the correction, Sargan test statistic cannot be computed. To overcome this limit, we rely on the Hansen J test using `xtabond2` stata command. The validity and total number of instruments are shown in the result tables.

Next, a description on how the different sectoral elasticities are derived is given.<sup>11</sup> In the equation (1), the short-run elasticity of various economic indicator with respect to the gas price ratio is  $\beta_1 * I_{i,2006}$ . We obtain as many different short run elasticities as sectors, thanks to the energy-intensity measure. We also obtain as many different long-run elasticities as sectors by assuming that the variables are stationary. Therefore, the long-run elasticity of various economic indicator with respect to the gas price ratio is  $((\beta_1 + \beta_2)/1 - \gamma) * I_{i,2006}$ .<sup>12</sup> Finally, we compute the overall long-run elasticity of the whole manufacturing sector using the equation (5).<sup>13</sup> It adjusts the different sectoral elasticities by the size of each manufacturing sector’s share in the economy (measured as the ratio of sectoral value added to total value added of all sectors).

$$Overall\_Elasticity = \sum_{i=1}^{79} Long\_term\_Elasticity_i * Sector\_share_i \quad (5)$$

## 4 Empirical results

In this section, we first address a detailed analysis of the impact of natural gas price ratio on capital expenditure variable. Then, on the basis of the methods outlined below, the reader can refer to the Appendix

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<sup>11</sup>In order to control for structural breaks, Chow-type tests are performed to assess the evidence of breaks in the estimated functions. The results are given in table 10 and 11 in the Appendix.

<sup>12</sup>The delta method estimates the standard errors of transformations of a random variable using a first-order Taylor approximation. Regression coefficients are random variables, we can use the delta method to approximate the standard errors of their transformations.

<sup>13</sup>These elasticities are available in the Appendix table 13.

regarding the results of the different explanatory variables. Secondly, we discuss the long-run elasticities of different sectors and their aggregate impact on the whole manufacturing sector.

#### 4.1 GMM results

Theoretically, we expect the coefficients to be negative and significant for the capital expenditure, industrial output, employment and export variables as a drop in relative natural gas prices would lead firms to invest more, produce more, hire more and export more. However, the coefficient should be positive and significant for imports because a drop in natural gas prices would lead to a drop in US gas prices and discourage imports from overseas manufactured goods.

Table 1 presents the effect of the shale gas boom on capital expenditure. The estimated effect is negative and significant for different measures of energy-intensity. Hereafter, we discuss the results obtained from gas-intensive measure per dollar of value added. The estimated coefficient implies that, in the case of Nitrogenous Fertilizers industry, which has the highest gas-intensity, investment expands by  $300.09 * 0.0037 = 1.11\%$  in the short term, for every dollar decrease in the relative price gap. In the long-term, investment expands by  $((0.0037 + 0)/(1 - 0.316)) * 300.09 = 1.66\%$  for every dollar that the relative price gap decrease. With this long-term elasticities, we can compute the overall impact of the change in the relative price of natural gas over the period 2006-2013. Knowing that relative natural gas prices fell by about 65%, the exact percentage change in capital expenditure variable, for Nitrogenous Fertilizers, is  $1.66 * 65 = 107.9\%$ . Thus, capital expenditure has increased about twofold. Table 1 shows qualitatively the same results for the other three intensity measures. Finally, the overall impact on the manufacturing sector is calculated from a weighted average, which is based on industry's share of either (i) total value added and (ii) total shipments. Investment expenditure increased between 1.65% and 3.26% depending on the intensity measures used, as a result of the shale gas boom. The use of two intensity measures (natural gas and total energy) takes into account the fact that total energy-intensive industries (using oil, gas and coal) can substitute other energy sources for natural gas. Finally, before the substitution effect, we obtain the lower bound impact and with the substitution effect taken into account, we have the upper bound impact over the entire period.

In addition, all the diagnostic statistics are satisfactory. Specifically, the Hansen J test does not reject the over identification restrictions; the absence of first-order serial correlation is rejected, while the absence of second-order serial correlation is not rejected.<sup>14</sup> Moreover, the lagged dependent variable has positive and statistically significant coefficients in all regressions. These coefficients are quite small and statistically

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<sup>14</sup>The results about serial correlation are not tabled in order to save space. Full results are available from the author upon request.

different from unity, suggesting a weak persistence. Moreover, De Hoyos and Sarafidis (2006) point out that when there is a cross-sectional dependence in the error term, any estimate technique relying on the instrumental variable and the generalized method of moments (GMM) such as Arellano and Bond (1991) are inconsistent. We run various standard tests for cross-sectional dependence proposed by Pesaran (2004) and Frees (1995), that do not reject the absence of cross-sectional independence. Therefore, we conclude from the diagnostic statistics that the system GMM is an appropriate estimator for our analysis.

The results of the rest of activity measures (industrial production, employment, exports and imports) are presented in the Appendix. As expected, industrial production, employment and export, following the decline in relative natural gas prices, lead firms to produce more, hire more and export more. As for import, a decline in natural gas prices causes US companies to lower their prices and discourages imports of foreign manufactured goods.

To address the impact of shale gas revolution over the period 2006-2013, we focus on long-term elasticities in the following section.

Table 1: Estimation results for capital expenditure

Estimation method	GMM-IV (Arellano-Bond)			
	Natural gas per \$ of Value added	Natural gas per \$ of Shipments	Total energy per \$ of Value added	Total energy per \$ of Shipments
$Capital\_E_{i,t-1}$	0.316** (2.19)	0.322** (2.24)	0.303** (2.19)	0.309** (2.21)
$(NG^{USA}/NG^{EUR})_t$	-0.0037*** (-7.02)	-0.0136*** (-5.52)	-0.0024** (-2.23)	-0.0059* (-1.80)
$(NG^{USA}/NG^{EUR})_{t-1}$	0.0014* (1.77)	0.007 (1.60)	0.00056 (0.91)	0.0024 (1.50)
Time fixed effects	Yes	Yes	Yes	Yes
Sectors	78		79	
Observations	1014		1027	
Time Period	1999-2011		1999-2011	
Total elasticity	-0,019	-0,030	-0,042	-0,050
Growth_rate <sub>2006-2013</sub>	1.26	1,95	2,76	3,26
Number of instruments	38			
Hansen J statistic	21.89	22.13	20.83	20.60
	<i>No Reject H<sub>0</sub></i>			
Cross sectional independence test: Pesaran	(-1.320)	(-1.351)	(-1.433)	(-1.437)
Cross sectional independence test: Frees	(0.961)	(0.978)	(1.066)	(1.100)

Note: t-stat are in (); \*, \*\* and \*\*\* denote the significance levels at 10%, 5%, 1%.



## 4.2 Long-term elasticities results

### Gas-intensive measure

This section focuses on the presentation and interpretation of the long-term elasticities. Table 13 in the Appendix presents the long-run elasticities for all variables of the US manufacturing sectors, with respect to the natural gas price ratio. They are statistically significant at the 5% level and consistent with the expected signs. Indeed, industrial production, employment, capital spending and exports have all increased with the decline in the relative prices of natural gas, while imports have declined. As a result of our estimation strategy, the response to shale gas operations varies greatly between sectors according to their energy intensity. It was associated with approximately a two-fold and a 0.03% increase in capital spending; a three-fold and 0.06% rise in industrial production; a 59% and 0.015% increase in exports; and a rise of 13% and 0.003% of employment for the most gas-intensive<sup>15</sup> and the least gas-intensive<sup>16</sup> industries, respectively. The imports decreased by 61% and 0.015% for the most gas-intensive and the least gas-intensive industries, respectively.

Table 2 gives the long-term elasticities of the top 20 gas-intensive industries for all the variables.<sup>17</sup> The first point is about the high elasticity of the nitrogenous fertilizers, due to outsized energy intensity of its production, which itself is linked to the outsize use of methane from natural gas to produce ammonia. In order to check that the results here are not mainly driven by this industry, the response of the variables for a sample that does not include this industry is computed. The results still hold without this industry, therefore they are not driven by a potential outlier.<sup>18</sup> The second point is about the asymmetric response of the variables to the price decline. Actually, the variables fall into two groups: the first group includes investment spending and industrial production, which are relatively more responsive to lower prices than the second group, which includes exports, imports, and employment. The results also show that shale gas boom has a larger effect on the domestic market than on the international market. The average long-term elasticities for the top 20 gas-intensive for industrial production (-0.36) and capital expenditure (-0.17) are higher than for exports (-0.0931) and imports (0.0972). In addition, elasticities of capital expenditure (-0.17) are significantly higher than those of employment (-0.018). This difference may be related to the greater weight of capital-intensive industries. Indeed, the manufacturing sector is made up of heavy industries such as chemicals and plastics, steel production, oil refining and many others, which require large investments to enter the market. It explains the small impact of the fall in gas prices on employment.

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<sup>15</sup>Nitrogenous Fertilizers

<sup>16</sup>Tabacco

<sup>17</sup>See table 13 in Appendix for more details.

<sup>18</sup>Results are available upon request.

Table 2: Long-term elasticity for the 20 most gas-intensive sectors (total gas consumption)

Industries	IP	CE	Emp	Exp	Imp
Nitrogenous Fertilizers	-3.5479	-1.6683	-0.1989	-0.9046	0.9440
Alkalies and Chlorine	-0.5117	-0.2406	Nd	-0.1305	0.1361
Carbon Black	-0.3743	-0.1760	Nd	-0.0954	0.0996
Flat Glass	-0.3477	-0.1635	-0.0194	-0.0886	0.0925
Glass Containers	-0.2244	-0.1055	-0.0125	-0.0572	0.0597
Ethyl Alcohol	-0.2114	-0.0994	-0.0118	-0.0539	0.0562
Gypsum	-0.1953	-0.0918	-0.0109	-0.0498	0.0519
Other Basic Organic Chemicals	-0.1858	-0.0874	-0.0104	-0.0473	0.0494
Industrial Gases	-0.1819	-0.0855	-0.0102	-0.0464	0.0484
Plastics Materials and Resins	-0.1811	-0.0851	-0.0101	-0.0461	0.0482
Phosphatic Fertilizers	-0.1808	-0.0850	-0.0101	-0.0461	0.0481
Secondary Smelting and Alloying of Aluminum	-0.1631	-0.0767	-0.0091	-0.0416	0.0434
Wet Corn Milling	-0.1497	-0.0704	-0.0083	-0.0381	0.0398
Iron and Steel Mills	-0.1395	-0.0656	Nd	-0.0355	0.0371
Paperboard Mills	-0.1307	-0.0614	-0.0073	-0.0333	0.0347
Synthetic Rubber	-0.1243	-0.0584	-0.0069	-0.0317	0.0330
Alumina and Aluminum	-0.1228	-0.0577	-0.0068	-0.0313	0.0326
Noncellulosic Organic Fibers	-0.1188	-0.0558	Nd	-0.0302	0.0316
Aluminum Sheet. Plate and Foils	-0.1144	-0.0537	-0.0064	-0.0291	0.0304
Mineral Wool	-0.1030	-0.0484	-0.0057	-0.0262	0.0274
Glass Products from Purchased Glass			-0.0051		
Pulp Mills			-0.0048		
Nonmetallic Mineral Products			-0.0048		
Primary Metals			-0.0047		
$((\beta_1 + \beta_2)/1 - \gamma)$	-0.012** (-2.58)	-0.006*** (-5.163)	-0.001*** (-3.333)	-0.003*** (-3.928)	0.003** (2.064)
Average elasticity of the twenty most gas-intensive sectors	<b>-0.3654</b>	<b>-0.1718</b>	<b>-0.0182</b>	<b>-0.0931</b>	<b>0.0972</b>
Average elasticity of the twenty less gas-intensive sectors	<b>-0.0060</b>	<b>-0.0028</b>	<b>-0.0003</b>	<b>-0.0015</b>	<b>0.0016</b>

Note:  $((\beta_1 + \beta_2)/1 - \gamma) * I_{i,2006}$  corresponds to the computation of long-run elasticities of each dependent variable with respect to gas price ratio. However, we need to check the significance level of  $((\beta_1 + \beta_2)/1 - \gamma)$  using the delta method that estimates the standard errors of transformations of a random variable using a first-order Taylor approximation.

IP, CE, Emp, Exp, and Imp refers to industrial production, capital expenditure, employment, export and import, respectively. t-stat are in (); \*, \*\* and \*\*\* denote the significance levels at 10%, 5%, 1%.

Nd: Not-documented means that data were not available for specific industries.

Table 3 shows the weighted long-term elasticities and shale gas impact on the manufacturing sector as a whole, using gas-intensive measures. The results appear to be robust to two different measures of gas consumption, as there is a small gap in the response between them. The results show that the overall impact is relatively low, even with a large response from gas-intensive industries (see Table 2). industrial production shows an overall elasticity about -0.057, -0.030 for capital expenditure, -0.010 for exports, -0.003 for employment and 0.017 for imports. This small impact of shale gas revolution on the whole manufacturing sector is due to the small share of the top 20 gas-intensive industries in the total value added of the manufacturing sector.<sup>19</sup>

The total impact of a decline in the relative price of natural gas over the period of 2006-2013 is computed, taking into account the share of the value added and shipment of each sector in the economy. Results show an increase of 3.2% for IP, 1.60% for CE, 0.20% for Emp, 0.72% for exports and a decrease of 0.91% for imports (see Table 3). However, these responses using a gas-intensive measure do not take into account a possible substitution of coal and oil by gas that could occur due to lower gas prices. These findings indicate a minimal impact of shale gas revolution.

Table 3: Long-term elasticities and shale gas impact for 2006-2013 period (gas consumption)

Variables	IP		CE		Emp		Exp		Imp	
	NGVA	NGSH	NGVA	NGSH	NGVA	NGSH	NGVA	NGSH	NGVA	NGSH
Overall elasticity	-0.041	-0.057	-0.019	-0.030	-0.002	-0.003	-0.010	-0.011	0.010	0.017
Shale gas impact	2.68%	3.76%	1.26%	1.95%	0.14%	0.25%	0.68%	0.76%	-0.71%	-1.11%

Note : Overall elasticity is computed by weighting the different sectoral elasticities by the weight of each manufacturing sector in the economy. NGVA and NGSH corresponds to gas-intensity measures per dollar of value added and per dollar of shipments, respectively.

IP, CE, Emp, Exp, and Imp refers to industrial production, capital expenditure, employment, export and import, respectively.

### Total energy-intensity measure

Table 4 gives the long-term elasticities of the top 20 energy-intensive industries for all the variables. Using energy-intensive measures allow to take into account the substitution effect from other energy sources to natural gas. The elasticities results are robust, consistent, and of the expected signs. Moreover, the top 20 energy-intensive industries show some differences relative to the top 20 gas-intensive industries. First, the use of total energy consumption as a measure changes the industry rank order in the top 20. Some industries which are oil and coal intensive enter into the top 20 now. Second, the value-added share in the economy of the top 20 rose from 5% to 13%. This constitutes a significant increase of 8 percentage points, compared to top 20 intensive-gas sectors. Third, total energy consumption as a measure allows computation of the

<sup>19</sup>Figure 3 and Figure 4 in Appendix.

maximum impact that may result from the exploitation of shale gas, assuming that gas prices remain at low levels. Low gas prices are a signal for industries that are consuming oil and coal as substitute for natural gas, in the long-term.

Table 4: Long-term elasticity for the 20 most energy-intensive sectors (total energy consumption)

Industries	IP	CE	Emp	Exp	Imp
Type of energy	TEVA	TEVA	TEVA	TEVA	TEVA
Nitrogenous Fertilizers	-1.121	-1.081	-0.229	-0.349	0.621
Other Petroleum and Coal Products	-0.575	-0.554	-0.118	Nd	Nd
Carbon Black	-0.514	-0.495	Nd	-0.160	0.285
Lime	-0.435	-0.420	-0.089	-0.135	0.241
Pulp Mills	-0.410	-0.396	-0.084	-0.128	0.227
Plastics Materials and Resins	-0.250	-0.241	-0.051	-0.078	0.138
Paperboard Mills	-0.233	-0.225	-0.048	-0.073	0.129
Alkalies and Chlorine	-0.224	-0.216	Nd	-0.070	0.124
Petroleum Refineries	-0.217	-0.209	-0.044	-0.068	0.120
Petroleum and Coal Products	-0.198	-0.191	-0.040	-0.061	0.110
Cements	-0.190	-0.183	-0.039	-0.059	0.105
Electrometallurgical Ferroalloy Products	-0.169	-0.163	Nd	-0.053	0.094
Wet Corn Milling	-0.158	-0.152	-0.032	-0.049	0.088
Other Basic Organic Chemicals	-0.152	-0.147	-0.031	-0.047	0.084
Other Pressed and Blown Glass and Glassware	-0.148	-0.143	-0.030	-0.046	0.082
Newsprint Mills	-0.148	-0.143	-0.030	-0.046	0.082
Petrochemicals	-0.144	-0.138	-0.029	-0.045	0.080
Flat Glass	-0.141	-0.136	-0.029	-0.044	0.078
Paper Mills. except Newsprint	-0.128	-0.123	-0.026	-0.040	0.071
Iron and Steel Mills	-0.124	-0.119	Nd	-0.039	0.069
Industrial Gases			-0.025	-0.038	0.068
Sugar Manufacturing			-0.023		
Paper			-0.021		
Alumina and Aluminum			-0.019		
$((\beta_1 + \beta_2)/1 - \gamma)$	-0.004*** (-3.03)	-0.003** (-2.332)	-0.001*** (-3.267)	-0.001** (-2.54)	0.002** (2.200)
Average elasticity of the twenty most energy-intensive sectors	<b>-0.28</b>	<b>-0.27</b>	<b>-0.05</b>	<b>-0.08</b>	<b>0.14</b>
Average elasticity of the twenty less energy-intensive sectors	<b>-0.001</b>	<b>-0.004</b>	<b>-0.0009</b>	<b>-0.0014</b>	<b>0.0024</b>

Note:  $((\beta_1 + \beta_2)/1 - \gamma) * I_{i,2006}$  corresponds to the computation of long-run elasticities of each dependent variable with respect to gas price ratio. However, we need to check the significance level of  $((\beta_1 + \beta_2)/1 - \gamma)$  using the delta method that estimates the standard errors of transformations of a random variable using a first-order Taylor approximation.

IP, CE, Emp, Exp, and Imp refers to industrial production, capital expenditure, employment, export and import, respectively. t-stat are in (); \*, \*\* and \*\*\* denote the significance levels at 10%, 5%, 1%.

Nd: Not-documented means that data were not available for specific industries.

Table 5 shows the weighted long-term elasticities and shale gas impact on the manufacturing sector as a whole, using energy-intensive measures. The overall impact is greater for all the variables when we assume that oil and coal consuming industries became exclusively gas consuming industries. Actually, except for

industrial production which is unchanged, investment increases by 3% instead of 1.60%, employment by 0.61% instead of 0.20%, exports by 1.6% instead of 0.72% and finally imports by 1.65% instead of 0.91%. This overall effect may be characterized as a maximal effect that may occur if the substitution process is achieved totally by all industries.

TABLE 5: Long-term elasticities and shale gas impact for 2006-2013 period (total energy consumption)

Variables	IP		CE		Emp		Exp		Imp	
Measures	TEVA	TESH	TEVA	TESH	TEVA	TESH	TEVA	TESH	TEVA	TESH
overall elasticity	-0.044	-0.054	-0.042	-0.050	-0.0085	-0.0103	-0.014	-0.035	0.025	NS
Shale gas impact	2.86%	3.52%	2.76%	3.26%	0.56%	0.67%	0.90%	2.30%	-1.65%	NS

Note : Overall elasticity is computed by weighting the different sectoral elasticities by the weight of each manufacturing sector in the economy. TEVA and TESH corresponds to energy intensity measures per dollar of value added and per dollar of shipments, respectively. IP, CE, Emp, Exp, and Imp refers to industrial production, capital expenditure, employment, export and import, respectively. NS: Not significant. It indicates that the coefficients resulting from this intensity measure is not significant at the 5% level.

### 4.3 Discussion

The aggregate effect is computed using equation 5. It is a weighted average of the effects of each sector, based on the share of each sector in total value added of all manufacturing sectors in 2011. As detailed in Table 3 and Table 5, the results show that the total effect on the manufacturing sectors as whole is relatively low. This is due to the limited share of the most energy-intensive industries in the total value added of the manufacturing sectors. To better appreciate how energy-intensive industries fit into the US manufacturing sector, we now examine the 20 most gas-intensive versus the 20 least gas-intensive industries out of the 79 industries in our sample. The first group of industries accounts for 5% of the total value added of manufacturing sectors, while the second group represents 45%. This weight distribution strongly minimises the impact of shale gas on the manufacturing sector as a whole. Indeed, whatever the gain for the most gas-intensive industries, it accounts for only a tiny share of total value added. In other words, the US manufacturing sector is dominated by low gas-intensive industries. Finally, claiming a revival of the US manufacturing sector would be premature, even when considering the impact with the substitution effect. However, the revival of some of the most gas-intensive industries is an undeniable fact.

Overall, our results are broadly consistent with previous studies. Celasun et al. (2014) shows that a reduction of 50% in the relative prices of natural gas leads to a 1.5% increase in industrial production, and the results of Morse et al. (2012) show a 3% increase in manufacturing output. Nevertheless, our study highlights two significant differences with Arezki et al. (2017). We find that exports increase by 0.72% while they find a 10% increase. Similarly, they show no impact on imports, while we identify a decreased impact

of roughly 0.9%. These differences could result from either (i) not taking into account the possibility of a structural break in their estimate and (ii) not taking into account a measure of gas consumption close to the positive gas supply shock of 2006. We have checked for structural breaks for the five economic variables. But it is confirmed only for the export and import variables (see Tables 10 and 11 in the Appendix). It means that the nature of the relationship between exports, imports, and natural gas prices over the period 2006-2013 is different to the period 1997-2005. The break point occurred in 2006, which coincided with the boom of shale gas in the US market.

Now, we discuss our results with regard to the literature that assesses the impacts of shale gas at the regional level, although this is slightly different from our study. The empirical literature evaluating the regional outcomes of the shale boom has expanded in recent years. These studies use different methods and focus on specific geographic locations to assess the impact of the shale gas boom on different socio-economic outcomes. Several studies show a positive effect on total local employment resulting from shale development in the United States. Among them, Weber (2014) studies the southern central zone of the United States where Weber (2012) and Brown (2014) are devoted to the central area of the United States. Maniloff et al. (2014) estimate that the shale boom created about 220,000 local jobs in boom areas. However, these impacts, whether on employment or even on income, are limited overall to the oil and gas industry (Feyrer et al., 2017). Positive spillovers can also occur in sectors not directly related to the extractive activity, but this limits to the construction, transport and leisure sectors (Feyrer et al., 2017).

In the manufacturing sector, spillovers effect at regional level may be negative. Wages in the oil and gas industries are generally higher than those offered by agriculture, manufacturing or services in those regions. As a result, the negative impact on employment in the trade sector is likely due to workers moving from these industries to the better-paid oil and gas sector. As Cosgrove et al. (2015) and DeLeire et al. (2014) pointed out, the tradable manufacturing sector shrunk due to the boom in shale gas in the Marcellus shales. Alternatively, some studies show that either the shale boom produced a beneficial employment spillover to the traded sector or did not negatively affect it (Weber, 2014; Brown, 2014). There is a high degree of heterogeneity in the conclusions of the various studies on the impacts of shale gas at the regional level. This may be due to differences in the initial conditions of the different regions in addition to different estimation methods. Berry et al. (2019) emphasizes that regions with less favorable geography tend to benefit more from the development of natural resources than those with more favorable geography, which would reconcile the diverging findings of the literature.

Finally, the results at the micro level support ours, the effect of shale gas is substantial on a few industries (extraction, construction, transport, leisure) but is low or even negative on the manufacturing sector.

## 5 Conclusion

This study measures the impact of shale gas on the US manufacturing sector through different economic variables. The economic benefit of shale gas development is assumed to be captured by the natural gas price differential between the US and Europe. The results show that the impact of shale gas revolution on the US manufacturing sector as a whole has been relatively low. However, the impact is very significant for the most gas-intensive manufacturing industries, which account only for a small share of total manufacturing value added. The revival of some of the most gas-intensive industries is an undeniable fact. Yet, claiming there has been a renaissance of US manufacturing sector would be premature.

As in the case of electric sector where shale gas is gradually replacing coal for electricity generation, financial incentives are needed to encourage the use of large amount of natural gas by the rest of industries that represent 95% of the total value added.<sup>20</sup> In a world where growth and sustained development matters now more than ever, shale gas may be a key player in the transition path between nowadays energy mix and hopeful futur that would chiefly involve renewable energy sources. On top of the direct effect on climate change, implementing such policy would also increase the overall effect of shale gas exploitation on US manufacturing sector which may lead to its revival.

The US shale revolution, together with the lifting of the ban on US crude oil and natural gas exports since December 2015, could be a game-changer and could revive a new kind of trade policy issues that the United States did not have to consider for decades. Is it going to offset the new energy cost advantage of the US manufacturing industry? Is the energy security of the United States under threat? These questions are of major importance and need to be analyzed in further research.

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<sup>20</sup>Coal-fired power plants produced more than half of the total electricity supply in 1990, and natural gas-fired power plants 12%; in 2013, the figures are respectively 29% and 27% (Energy Information Administration, 2014).

## References

- Arellano, M. and S. Bond (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *The Review of Economic Studies* 58, 277–297.
- Arezki, R., T. Fetzner, and F. Pisch (2017). On the comparative advantage of US manufacturing: Evidence from the shale gas revolution. *Journal of International Economics* 107, 34–59.
- Aruga, K. (2016). The US shale gas revolution and its effect on international gas markets. *Journal of Unconventional Oil and Gas Resources* 14, 1–5.
- Asche, F., P. Osmundsen, and M. Sandsmark (2006). The UK market for natural gas, oil and electricity: Are the prices decoupled? *The Energy Journal*, 27–40.
- Asche, F., P. Osmundsen, and R. Tveterås (2002). European market integration for gas? Volume flexibility and political risk. *Energy Economics* 24, 249–265.
- Bazilian, M., A. Brandt, L. Billman, G. Heath, J. Logan, M. Mann, M. Melaina, P. Statwick, D. Arent, and S. Benson (2014). Ensuring benefits from North American shale gas development: Towards a research agenda. *Journal of Unconventional Oil and Gas Resources* 7, 71–74.
- Berry, K., A. James, B. Smith, B. Watson, et al. (2019). Geography, geology, and regional economic development.
- Brown, J. P. (2014). Production of natural gas from shale in local economies: A resource blessing or curse? *Economic Review-Federal Reserve Bank of Kansas City*, 5.
- Caporin, M. and F. Fontini (2017). The long-run oil–natural gas price relationship and the shale gas revolution. *Energy Economics* 64, 511–519.
- Celasun, O., M. G. Di Bella, T. Mahedy, and C. Papageorgiou (2014). *The US Manufacturing Recovery: Uptick or Renaissance?* International Monetary Fund.
- Cornot-Gandolphe, S. (2013). The impact of the development of shale gas in the United States on Europe’s petrochemical industries. *IFRI Centre for Energy*. <http://www.ifri.org/en/node/7073>.
- Cosgrove, B. M., D. R. LaFave, S. T. Dissanayake, and M. R. Donihue (2015). The economic impact of shale gas development: A natural experiment along the New York-Pennsylvania border. *Agricultural and Resource Economics Review* 44, 20–39.



- De Hoyos, R. E. and V. Sarafidis (2006). Testing for cross-sectional dependence in panel-data models. *The Stata Journal* 6, 482–496.
- DeLeire, T., P. Eliason, and C. Timmins (2014). Measuring the employment impacts of shale gas development. *McCourt School of Public Policy, Georgetown University*.
- Energy Information Administration, U. (2007). Short-Term Energy Outlook Supplement.
- Energy Information Administration, U. (2015). Annual Energy Outlook 2015.
- Erdős, P. (2012). Have oil and gas prices got separated? *Energy Policy* 49, 707–718.
- Feyrer, J., E. T. Mansur, and B. Sacerdote (2017). Geographic dispersion of economic shocks: Evidence from the fracking revolution. *American Economic Review* 107, 1313–34.
- Frees, E. W. (1995). Assessing cross-sectional correlation in panel data. *Journal of Econometrics* 69, 393–414.
- Houser, T. and S. Mohan (2013). *Fueling Up: The economic implications of America’s oil and gas boom*. Columbia University Press.
- Hu, D. and S. Xu (2013). Opportunity, challenges and policy choices for china on the development of shale gas. *Energy Policy* 60, 21–26.
- Hulshof, D., J. P. van der Maat, and M. Mulder (2016). Market fundamentals, competition and natural-gas prices. *Energy Policy* 94, 480–491.
- Kinnaman, T. C. (2011). The economic impact of shale gas extraction: A review of existing studies. *Ecological Economics* 70(7), 1243–1249.
- Li, R., R. Joyeux, and R. D. Ripple (2014). International natural gas market integration. *The Energy Journal*, 159–179.
- Lochner, S. and D. Bothe (2009). The development of natural gas supply costs to Europe, the United States and Japan in a globalizing gas market—Model-based analysis until 2030. *Energy Policy* 37, 1518–1528.
- Maniloff, P., R. Mastro Monaco, et al. (2014). The local economic impacts of hydraulic fracturing and determinants of dutch disease. *Division of Economic and Business Working Paper Series, Colorado School of Mines*.
- Maxwell, D. and Z. Zhu (2011). Natural gas prices, LNG transport costs, and the dynamics of LNG imports. *Energy Economics* 33, 217–226.

- Maya, J. R. L. (2013). The United States experience as a reference of success for shale gas development: The case of Mexico. *Energy Policy* 62, 70–78.
- Morse, E. L., E. G. Lee, D. P. Ahn, A. Doshi, S. M. Kleinman, and A. Yuen (2012). Energy 2020: North America, the New Middle East. *Citi Global Perspectives & Solutions* 20.
- Nickell, S. (1981). Biases in dynamic models with fixed effects. *Econometrica*, 1417–1426.
- Pesaran, M. H. (2004). General diagnostic tests for cross section dependence in panels. Cambridge working papers, University of Cambridge.
- Rahm, B. G., J. T. Bates, L. R. Bertoia, A. E. Galford, D. A. Yoxtheimer, and S. J. Riha (2013). Wastewater management and marcellus shale gas development: Trends, drivers, and planning implications. *Journal of Environmental Management* 120, 105–113.
- Regnard, N. and J.-M. Zakoian (2011). A conditionally heteroskedastic model with time-varying coefficients for daily gas spot prices. *Energy Economics* 33(6), 1240–1251.
- Sendich, E. (2014). The importance of natural gas in the industrial sector with a focus on energy-intensive industries. *U.S. Energy Information Administration*.
- Vengosh, A., R. B. Jackson, N. Warner, T. H. Darrah, and A. Kondash (2014). A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States. *Environmental Science & Technology* 48, 8334–8348.
- Villar, J. A. and F. L. Joutz (2006). The relationship between crude oil and natural gas prices. *U.S. Information Administration*, 1–43.
- Wakamatsu, H. and K. Aruga (2013). The impact of the shale gas revolution on the US and Japanese natural gas markets. *Energy Policy* 62, 1002–1009.
- Wang, Q., X. Chen, A. N. Jha, and H. Rogers (2014). Natural gas from shale formation—The evolution, evidences and challenges of shale gas revolution in United States. *Renewable and Sustainable Energy Reviews* 30, 1–28.
- Weber, J. G. (2012). The effects of a natural gas boom on employment and income in Colorado, Texas, and Wyoming. *Energy Economics* 34(5), 1580–1588.
- Weber, J. G. (2014). A decade of natural gas development: The makings of a resource curse? *Resource and Energy Economics* 37, 168–183.

# Appendix

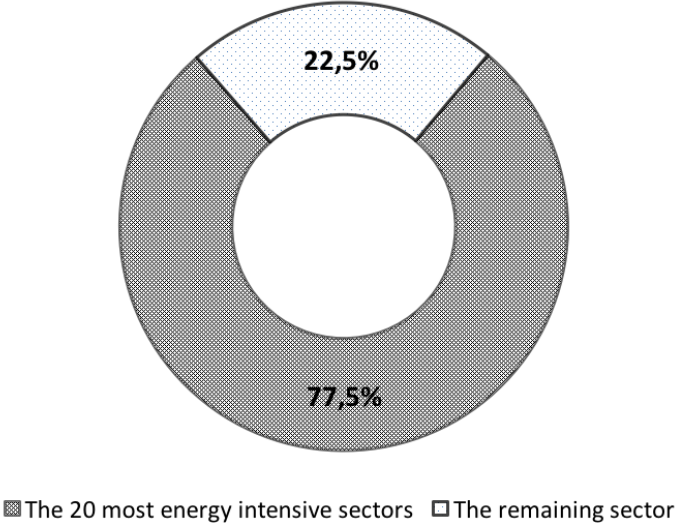


Figure 3: Share of energy intensity

Source: Author calculation

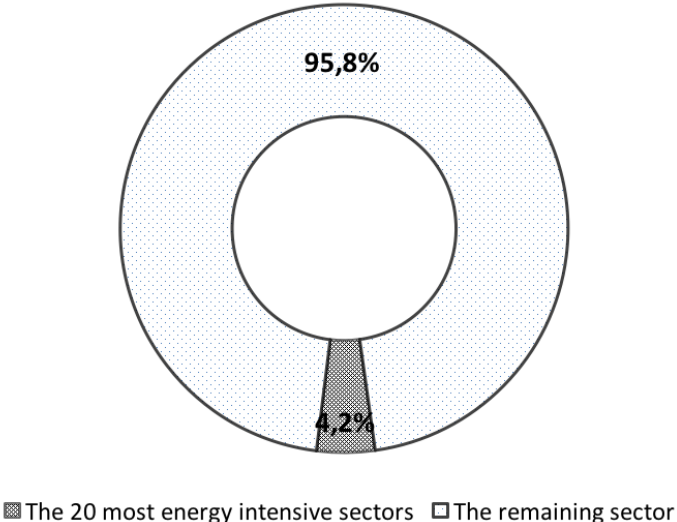


Figure 4: Share of value added

Source: Author calculation

TABLE 6: Energy intensity of 2006 (Thousand BTUs per \$ of Value Added and Shipments)

NAICS Code	Industries	Natural	Total	Natural	Total
		gas	energy	gas	energy
		per \$ of Value Added		per \$ of Shipments	
325311	Nitrogenous Fertilizers	300.09	309.31	87.44	90.12
325181	Alkalies and Chlorine	43.28	61.9	22.37	32
325182	Carbon Black	31.66	141.66	12.79	57.23
327211	Flat Glass	29.40	39.02	15.94	21.15
327213	Glass Containers	18.98	24.3	11.01	14.10
325193	Ethyl Alcohol	17.88	24.56	10.26	14.09
32742	Gypsum	16.52	18.7	9.72	11
325199	Other Basic Organic Chemicals	15.72	41.96	5.29	14.14
32512	Industrial Gases	15.39	33.76	8.48	18.60
325211	Plastics Materials and Resins	15.32	68.90	4.67	21.03
325312	Phosphatic Fertilizers	15.3	21.74	3.7	5.25
331314	Secondary Smelting and Alloying of Aluminum	13.8	16.1	2.31	2.7
311221	Wet Corn Milling	12.66	43.6	5.28	18.2
331111	Iron and Steel Mills	11.79	34.18	4.44	12.87
32213	Paperboard Mills	11.05	64.4	5.54	32.3
325212	Synthetic Rubber	10.51	17.8	3.54	6
3313	Alumina and Aluminum	10.39	25.52	2.83	6.97
325222	Noncellulosic Organic Fibers	10.05	21.57	3.9	8.37
331315	Aluminum Sheet, Plate and Foils	9.67	13.6	2.34	3.3
327993	Mineral Wool	8.71	12.7	5.49	8
327215	Glass Products from Purchased Glass	7.84	9.8	4.08	5.1
32211	Pulp Mills	7.358	113.2	3.24	49.9
327	Nonmetallic Mineral Products	7.28	17.64	4.03	9.77
331	Primary Metals	7.19	19.90	2.69	7.46
32411	Petroleum Refineries	7.13	59.92	1.53	12.92
31131	Sugar Manufacturing	6.87	31.3	2.67	12.2
324	Petroleum and Coal Products	6.75	54.57	1.52	12.32
331521	Aluminum Die-Casting Foundries	6.68	9.8	3.34	4.9
3112	Grain and Oilseed Milling	6.62	17.55	2.15	5.71
322121	Paper Mills, except Newsprint	6.54	35.3	3.63	19.6
331524	Aluminum Foundries, except Die-Casting	6.50	8.36	3.37	4.34
331316	Aluminum Extruded Products	5.84	8.6	1.7	2.5
322	Paper	5.81	28.9	2.75	13.7
325188	Other Basic Inorganic Chemicals	5.68	19.02	3.21	10.75
32741	Lime	5.17	120.1	3.26	75.8
325	Chemicals	5.16	15.22	2.77	8.17
3212	Veneer, Plywood, and Engineered Woods	4.68	17.6	1.81	6.8
322122	Newsprint Mills	4.53	40.8	2.32	20.9
32511	Petrochemicals	4.33	39.60	1.80	16.47
3114	Fruit and Vegetable Preserving and Specialty Foods	4.10	5.5	2.08	2.8
325192	Cyclic Crudes and Intermediates	3.80	8.8	2.20	5.1
3315	Foundries	3.69	8.30	2.07	4.67

Table 6 (continued)

331511	Iron Foundries	3.6	12.6	1.86	6.51
324199	Other Petroleum and Coal Products	3.44	158.50	1.14	52.70
313	Textile Mills	3.14	8.6	1.49	4.1
3312	Steel Products from Purchased Steel	3.023	6.51	1.14	2.47
3115	Dairy Products	2.94	4.3	0.89	1.3
314	Textile Product Mills	2.93	4.6	1.15	1.8
3116	Animal Slaughtering and Processing	2.81	4.38	1.02	1.59
32731	Cements	2.74	52.5	1.78	34
3314	Nonferrous Metals, except Aluminum	2.69	9.20	0.84	2.88
311	Food	2.68	5	1.18	2.2
331112	Electrometallurgical Ferroalloy Products	2.12	46.71	1.02	22.64
321	Wood Products	2.03	10.54	0.782	4.05
332	Fabricated Metal Products	1.57	2.59	0.78	1.29
326	Plastics and Rubber Products	1.40	3.71	0.64	1.70
321113	Sawmills	1.31	15.20	0.43	5.03
3219	Other Wood Products	1.21	5.68	0.54	2.53
325992	Photographic Film, Paper, Plate, and Chemicals	.95	3.8	.6	2.4
3121	Beverages	0.94	2.35	0.43	1.07
336	Transportation Equipment	0.88	1.69	0.311	0.59
335	Electrical Equip., Appliances, and Components	0.86	2.13	0.38	0.94
336111	Automobiles	0.80	1.5	0.21	0.4
336112	Light Trucks and Utility Vehicles	0.75	1.3	0.17	0.3
323	Printing and Related Support	0.68	1.5	0.45	1
312	Beverage and Tobacco Products	0.52	1.37	0.33	0.88
315	Apparel	0.5	1	0.25	0.5
333	Machinery	0.49	1.2	0.24	0.6
316	Leather and Allied Products	0.36	1.1	0.2	0.6
334413	Semiconductors and Related Devices	0.36	1.21	0.27	0.91
3364	Aerospace Product and Parts	0.35	0.91	0.15	0.40
3254	Pharmaceuticals and Medicines	0.34	0.68	0.26	0.51
337	Furniture and Related Products	0.31	1.11	0.17	0.61
325412	Pharmaceutical Preparation	0.29	0.6	0.24	0.5
336411	Aircraft	0.24	0.6	0.08	0.2
339	Miscellaneous	0.227	0.6	0.15	0.4
334	Computer and Electronic Products	0.223	0.704	0.12	0.40
3122	Tobacco	0.075	0.3	0.075	0.3
327212	Other Pressed and Blown Glass and Glassware		40.80		24.89

Table 7: Economic variables

Variables	Source	Units	Time Period	Matches for	
				MECS and NGI	MECS and TEI
Capital expenditure	Census annual survey manufacturers	Millions of \$	1997-2011	78	79
Industrial production	Board of Governors of the Federal Reserve System	Index, 2007=100	1997-2013	78	79
Employment	Quarterly Census of Employment and Wages	Thousands	1997-2012	78	79
Imports	U.S. International Trade Commission	Billions of \$	1997-2013	75	76
Exports	U.S. International Trade Commission	Billions of \$	1997-2013	75	76

NGI : Natural Gas intensity.

TEI : Total Energy intensity.

MECS : Manufacturing Energy Consumption Survey.

TABLE 8: Estimation results for employment

Estimation method	GMM-IV (Arellano-Bond)			
	Natural gas per \$ of Value added	Natural gas per \$ of Shipments	Total energy per \$ of Value added	Total energy per \$ of Shipments
$Employment_{i,t-1}$	0.566*** (6.48)	0.636*** (10.53)	0.564*** (4.84)	0.591*** (5.35)
$(NG^{USA}/NG^{EUR})_t$	-0.0000 (-0.65)	-0.0002 (-0.64)	-0.0001 (-1.17)	-0.0005 (-1.29)
$(NG^{USA}/NG^{EUR})_{t-1}$	-0.0002** (-2.32)	-0.0009** (-2.26)	-0.0003** (-2.39)	-0.0007** (-2.38)
Time fixed effects	Yes	Yes	Yes	Yes
Sectors	78		79	
Observations	1074		1088	
Time Period	1999-2012		1999-2012	
Total elasticity	-0.0021	-0.0038	-0.0085	-0.0103
Growth_rate <sub>2006-2013</sub>	0.14	0.25	0.56	0.67
Number of instruments	28			
Hansen J statistic	13.13	10.16	14.47	13.60
	<i>No Reject H<sub>0</sub></i>			
Cross sectional independence test : Pesaran	(-1.523)	(-1.529)	(-1.639)	(-1.654)*
Cross sectional independence test : Frees	(1.114)	(1.120)	(1.127)	(1.315)

Note : t-stat are in (); \*, \*\* and \*\*\* denote the significance levels at 10%, 5%, 1%, respectively.

TABLE 9: Estimation results for industrial production

Estimation method	GMM-IV (Arellano-Bond)			
Energy Intensity measure	Natural gas per \$ of Value added	Natural gas per \$ of Shipments	Total energy per \$ of Value added	Total energy per \$ of Shipments
$Indus\_produc_{i,t-1}$	0.867*** (6.28)	0.868*** (6.29)	0.853*** (5.96)	0.850*** (6.04)
$(NG^{USA}/NG^{EUR})_t$	-0.0006*** (-4.16)	-0.0023** (-3.71)	-0.0004* (-1.93)	-0.0013** (-1.99)
$(NG^{USA}/NG^{EUR})_{t-1}$	-0.0008*** (-11.46)	-0.0027*** (-8.20)	-0.0005** (-2.26)	-0.0010 (-1.38)
Time fixed effects	Yes	Yes	Yes	Yes
Sectors	78		79	
Observations	1170		1185	
Time Period	1999-2013		1999-2013	
Total elasticity	-0,041	-0,057	-0,044	-0,054
Growth_rate <sub>2006-2013</sub>	2,68	3,76	2,86	3,52
Number of instruments	31			
Hansen J statistic	15.17	15.21	15.04	15.02
	<i>No Reject H<sub>0</sub></i>			
Cross sectional independence test : Pesaran	(-1.416)	(-1.415)	(-1.430)	(-1.447)
Cross sectional independence test : Frees	(0.812)	(0.956)	(0.966)	(0.964)

Note : t-stat are in (); \*, \*\* and \*\*\* denote the significance levels at 10%, 5%, 1%, respectively.



TABLE 10: Estimation results for exports

Estimation method	GMM-IV (Arellano-Bond)			
Energy Intensity measure	Natural gas per \$ of Value added	Natural gas per \$ of Shipments	Total energy per \$ of Value added	Total energy per \$ of Shipments
$Exp_{i,t-1}$	0.679*** (6.20)	0.657*** (6.04)26.77**	0.682*** (4.30)	0.654*** (4.63)
$(NG^{USA}/NG^{EUR})_{t,97-05}$	0.0003 (0.92)	0.0012 (0.86)	0.0006** (1.87)	0.0021* (2.58)
$(NG^{USA}/NG^{EUR})_{t,06-2013}$	0.0003 (0.73)	0.0010 (0.66)	0.0007 (1.73)	0.0024* (1.91)
$(NG^{USA}/NG^{EUR})_{t-1,97-05}$	-0.0005*** (-3.46)	-0.0013 (-1.45)	-0.0006** (-2.11)	-0.0019** (-2.01)
$(NG^{USA}/NG^{EUR})_{t-1,06-2013}$	-0.0010*** (-3.83)	-0.0027* (-1.82)	-0.0009** (-2.28)	-0.0024* (-1.95)
Structural break	Yes	Yes	No	No
Time fixed effects	Yes	Yes	Yes	Yes
Sectors	75		76	
Observations	1125		1140	
Time period	1999-2013		1999-2013	
Total elasticity	-0.010	-0,011	-0.014	-0.035
Growth_rate <sub>2006-2013</sub>	0.68	0.76	0.90	2.30
Number of instruments	33			
Equality test of the coefficients	<i>Reject H<sub>0</sub></i>	<i>Reject H<sub>0</sub></i>	<i>No Reject H<sub>0</sub></i>	<i>No Reject H<sub>0</sub></i>
Hansen J statistic	11.68	9.65	38.90	13.54
	<i>No Reject H<sub>0</sub></i>			
Cross sectional independence test : Pesaran	(-1.214)	(-1.216)	(-1.216)	(-1.220)
Cross sectional independence test : Frees	(1.011)	(0.986)	(1.235)*	(1.156)

Note : t-stat are in ( ) ; \* , \*\* and \*\*\* denote the significance levels at 10% , 5% , 1% , respectively. Here we test the parameters null hypothesis of equality of the for the period 1997-2005 and 2006-2013. The rejection of  $H_0$  means that the parameters are different for the two periods. It proves the existence of a structural break.

TABLE 11: Estimation results for imports

Estimation method	GMM-IV (Arellano-Bond)			
Energy Intensity measure	Natural gas per \$ of Value added	Natural gas per \$ of Shipments	Total energy per \$ of Value added	Total energy per \$ of Shipments
$Imp_{i,t-1}$	0.517*** (2.71)	0.483** (2.55)	0.459** (2.57)	0.416** (2.46)
$(NG^{USA}/NG^{EUR})_{t,97-05}$	0.0004 (0.56)	-0.0002 (-0.06)	0.0004 (0.75)	-0.0000 (-0.02)
$(NG^{USA}/NG^{EUR})_{t,06-2013}$	0.0005 (0.71)	0.0001 (0.05)	0.0006 (0.98)	0.0003 (0.21)
$(NG^{USA}/NG^{EUR})_{t-1,97-05}$	0.0011*** (2.79)	0.0047** (2.11)	0.0007** (1.99)	0.0018 (1.49)
$(NG^{USA}/NG^{EUR})_{t-1,06-2013}$	0.0015*** (3.49)	0.0059*** (2.65)	0.0010*** (2.62)	0.0025 (1.87)
Structural break	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	No
Sectors	78		79	
Observations	1125		1140	
Time period	1999-2012		1999-2012	
Total elasticity	0.010	0.017	0.025	
Growth_rate <sub>2006-2013</sub>	-0.71	-1.11	-1.65	
Number of instruments	61			
Equality test of the coefficients	<i>Reject H<sub>0</sub></i>	<i>Reject H<sub>0</sub></i>	<i>Reject H<sub>0</sub></i>	<i>No Reject H<sub>0</sub></i>
Hansen J statistic	50.56	51.30	50.69	50.88
	<i>No Reject H<sub>0</sub></i>			
Cross sectional independence test : Pesaran	(-1.217)	(-1.210)	(-1.320)	(-1.125)
Cross sectional independence test : Frees	(1.023)	(1.115)	(1.116)	(1.119)

Note : t-stat are in ( ) ; \* , \*\* and \*\*\* denote the significance levels at 10%, 5%, 1%, respectively. Here we test the parameters null hypothesis of equality of the for the period 1997-2005 and 2006-2013. The rejection of  $H_0$  means that the parameters are different for the two periods. It proves the existence of a structural break.

TABLE 12: Comparison of estimators for exports (Nickell bias)

Estimation method	MCO	Within	Arellano-Bond	Anderson-Hsiao
Energy Intensity measure	Natural gas per \$ of Value added			
$Exp_{i,t-1}$	0.996*** (237.75)	0.889*** (40.00)	0.740 *** (7.96 )	0.714 (0.82)
$(NG^{USA}/NG^{EUR})_t$	0.0007** (5.11)	0.0010*** (5.45)	-0.0005 (-1.46)	-0.00005 (-0.04)
$(NG^{USA}/NG^{EUR})_{t-1}$	-0.00079*** (-5.55)	-0.0006426*** (-4.00)	-0.0010*** (-3.43)	-0.0010 (-0.80)
Constant	0.121 (1.34 )	2.327*** (4.90)	5.894*** (2.85)	0.018 (0.32)
Time fixed effects	No	Yes		
Sectors	75			
Observations	1200		1125	
Time period	1998-2013		1999-2013	
Number of instruments	0		80	17

Note : t-stat are in (); \*, \*\* and \*\*\* denote the significance levels at 10%, 5%, 1%, respectively. Theoretically the estimator of Anderson-Hsiao underestimates the coefficient of the lagged variable and the OLS overestimates it. The Arellano-Bond estimation must be between them. We are in this case, confirming the robustness of our results. The estimator within meanwhile suffers from a bias known as Nickell bias.

TABLE 13: Long-term elasticities (Thousand Btus per \$ of Value Added)

Industry	IP	Ca	Emp	Exp	Imp
Nitrogenous Fertilizers	-3.548	-1.668	-0.199	-0.905	0.944
Alkalies and Chlorine	-0.512	-0.241		-0.131	0.136
Carbon Black	-0.374	-0.176		-0.095	0.100
Flat Glass	-0.348	-0.164	-0.019	-0.089	0.093
Glass Containers	-0.224	-0.106	-0.013	-0.057	0.060
Ethyl Alcohol	-0.211	-0.099	-0.012	-0.054	0.056
Gypsum	-0.195	-0.092	-0.011	-0.050	0.052
Other Basic Organic Chemicals	-0.186	-0.087	-0.010	-0.047	0.049
Industrial Gases	-0.182	-0.086	-0.010	-0.046	0.048
Plastics Materials and Resins	-0.181	-0.085	-0.010	-0.046	0.048
Phosphatic Fertilizers	-0.181	-0.085	-0.010	-0.046	0.048
Secondary Smelting and Alloying of Aluminum	-0.163	-0.077	-0.009	-0.042	0.043
Wet Corn Milling	-0.150	-0.070	-0.008	-0.038	0.040
Iron and Steel Mills	-0.140	-0.066		-0.036	0.037
Paperboard Mills	-0.131	-0.061	-0.007	-0.033	0.035
Synthetic Rubber	-0.124	-0.058	-0.007	-0.032	0.033
Alumina and Aluminum	-0.123	-0.058	-0.007	-0.031	0.033
Noncellulosic Organic Fibers	-0.119	-0.056		-0.030	0.032
Aluminum Sheet, Plate and Foils	-0.114	-0.054	-0.006	-0.029	0.030
Mineral Wool	-0.103	-0.048	-0.006	-0.026	0.027
Glass Products from Purchased Glass	-0.093	-0.044	-0.005	-0.024	0.025
Pulp Mills	-0.087	-0.041	-0.005	-0.022	0.023
Nonmetallic Mineral Products	-0.086	-0.041	-0.005	-0.022	0.023
Primary Metals	-0.085	-0.040	-0.005	-0.022	0.023
Petroleum Refineries	-0.084	-0.040	-0.005	-0.022	0.022
Sugar Manufacturing	-0.081	-0.038	-0.005	-0.021	0.022
Petroleum and Coal Products	-0.080	-0.038	-0.004	-0.020	0.021
Aluminum Die-Casting Foundries	-0.079	-0.037			
Grain and Oilseed Milling	-0.078	-0.037	-0.004	-0.020	0.021
Paper Mills, except Newsprint	-0.077	-0.036	-0.004	-0.020	0.021
Aluminum Foundries, except Die-Casting	-0.077	-0.036	-0.004	-0.020	0.020
Aluminum Extruded Products	-0.069	-0.033		-0.018	0.018
Paper	-0.069	-0.032	-0.004	-0.018	0.018
Other Basic Inorganic Chemicals	-0.067	-0.032		-0.017	0.018
Lime	-0.061	-0.029	-0.003	-0.016	0.016
Chemicals	-0.061	-0.029	-0.003	-0.016	0.016
Veneer, Plywood, and Engineered Woods	-0.055	-0.026	-0.003	-0.014	0.015
Newsprint Mills	-0.054	-0.025	-0.003	-0.014	0.014
Petrochemicals	-0.051	-0.024	-0.003	-0.013	0.014
Fruit and Vegetable Preserving and Specialty Foods	-0.048	-0.023	-0.003	-0.012	0.013
Cyclic Crudes and Intermediates	-0.045	-0.021		-0.011	0.012
Foundries	-0.044	-0.021	-0.002	-0.011	0.012
Iron Foundries	-0.043	-0.020	-0.002	-0.011	0.011
Other Petroleum and Coal Products	-0.041	-0.019	-0.002		

Table 13 (continued)

Steel Products from Purchased Steel	-0.036	-0.017	-0.002	-0.009	0.010
Dairy Products	-0.035	-0.016	-0.002	-0.009	0.009
Textile Product Mills	-0.035	-0.016	-0.002	-0.009	0.009
Animal Slaughtering and Processing	-0.033	-0.016	-0.002	-0.008	0.009
Cements	-0.032	-0.015	-0.002	-0.008	0.009
Nonferrous Metals, except Aluminum	-0.032	-0.015	-0.002	-0.008	0.008
Food	-0.032	-0.015	-0.002	-0.008	0.008
Electrometallurgical Ferroalloy Products	-0.025	-0.012		-0.006	0.007
Wood Products	-0.024	-0.011	-0.001	-0.006	0.006
Fabricated Metal Products	-0.019	-0.009	-0.001	-0.005	0.005
Plastics and Rubber Products	-0.017	-0.008	-0.001	-0.004	0.004
Sawmills	-0.016	-0.007	-0.001	-0.004	0.004
Other Wood Products	-0.014	-0.007	-0.001	-0.004	0.004
Photographic Film, Paper, Plate, and Chemicals	-0.011	-0.005	-0.001	-0.003	0.003
Beverages	-0.011	-0.005	-0.001	-0.003	0.003
Transportation Equipment	-0.010	-0.005	-0.001	-0.003	0.003
Electrical Equipment, Appliances, and Components	-0.010	-0.005	-0.001	-0.003	0.003
Automobiles	-0.010	-0.004	-0.001	-0.002	0.003
Light Trucks and Utility Vehicles	-0.009	-0.004	-0.001		
Printing and Related Support	-0.008	-0.004	0.000	-0.002	0.002
Beverage and Tobacco Products	-0.006	-0.003	0.000	-0.002	0.002
Apparel	-0.006	-0.003	0.000	-0.002	0.002
Machinery	-0.006	-0.003	0.000	-0.001	0.002