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« Long-term macroeconomic impact of US unconventional Oil and Gas production : a general equilibrium perspective »

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Abstract

The shale gas and oil revolution in the United States has given hope of a new source of energy abundance for countries rich in these resources. In Europe in particular, several countries have undertook explorations with the idea of supporting economic growth and industrial competitiveness by producing cheaper energy. In this article, we conduct a prospective analysis of the long-term economic impact of shale oil and gas production in the United States. First, we quantify the limits of GDP increases due to technical inertia within the economy, separating the effect on oil and gas markets. In a second step, we analyze policies aiming at supporting competitiveness of highly exporting industries. Within the general equilibrium Imaclim-R model, when it comes to improve wellfare with the production of unconventionnal resource, we highlight a trade-off between industrial competitiveness on one hand, and global employment in the economy on the other hand,

1 Introduction

Neither energy experts nor governments anticipated the unconventional oil and gas revolution, which disrupted local energy markets[1]. From 2005 to 2014, shale gas raised the US gas output by nearly 30%, accounting for 35% of total gas production. With the slow down of the drilling activity in dry shale gas fields, light tight oil production boomed to 4.8 bbl/day in 2015 benefiting from a high rig availability and the same technological progress and regulations. The US became the first world oil producer with an average production of 9.3 bbl/day in 2015.,

This revolution undoubtedly boost the US economy, but to which extent ? In a context where the global economy show signs of recovery since the 2008 crisis, it remains difficult to assess how unconventional resources contribute to GDP growth in the US. Energy accounts for a small part of the economic activity of developed countries (3% of GDP for the US), but lower energy prices could lead to GDP gains by reducing production costs and households energy bill [2]. The sharp increase of unconventional gas production decreased the US natural well-head gas price from 6.73$/MBtu in 2006 to 3.73$/MBtu in 2013 (U.S. Energy Information Administration, 2014b), which benefited

[1]The International Energy Agency (IEA) published only in 2009 a special issue concerning unconventional gas resources its World Energy Outlook (IEA, 2009), mentioning “a golden age of gas” in its 2011 and 2012 special reports (IEA, 2011,0).

[2]For the specific case of shale gas, see Mason et al. (2014) for an overview of the different sources of benefits and costs

the electricity market : 15% of coal-fired power plants were directly substituted to gas-fired power plant (U.S. Energy Information Administration, 2014a, fig. 15). The overall GDP contribution of shale gas activity was estimated in 2010 to be $76 billion, and is expected to reach $231 billion by 2035 (IHS, 2011). Spencer et al. (2014) estimated shale gas activity to contribute to 0.84% increase in GDP in the long term. The US light tight oil production is partly responsible of the 50% oil price drop in the second half of 2014, along with the reaction of the OPEC and unanticipated global demand. M. Husain et al. (2015) estimated a +0.5% increase in global GDP if oil prices remain at this level. As for the US economy, light tight oil and unconventional gas resources production will increase GDP by 1.5% in the long-term (Hunt et al., 2015).

The effect on US competitiveness is less clear. Shale gas production is expected to support energy intensive exportations with lower energy prices. The drop in US gas price disconnected the US gas market from the rest of the world, and the electricity price remains stable, being now half of the European price (IEA, 2013, fig. 5.18). Arezki and Fetzer (2016) found a 6% increase in US manufacturing exports due to the gas price gap between the US and the rest of the world. But US gas intensive manufacturing sectors only accounts for 8.7% of the total manufacturing sectors in term of GDP, so the direct impact of lower gas prices will be limited (Spencer et al., 2014, fig. 16). Although there is no evidence so far, a risk of a resource curse is not unlikely (Corden, 1981; Corden and Neary, 1982).

Shale gas activity also supports direct and indirect job creation. IHS (2011) reported 600000 job created up to 2010, and projected 1.6 million units for 2035. Paredes et al. (2015) found a positive impact on employment in the Marcellus, while Weber (2012) found a modest increase of employment (2.35 jobs per million dollars in gas production) in three counties in Western states. Kinnaman (2011) noted that those non-academic estimations are likely to be overestimated, and should be taken with cautious. The resurgence of the US manufacturing sector also supported job creation, but only slightly [3].

How does GDP and employment contribution of shale oil and gas production to the US economy ? Does lower energy prices support the US competitiveness ? In this article, we assess the long-term benefits of oil and gas unconventional resource production for the US economy. We use a general equilibrium framework incorporating bottom-up information of specific energy sectors in a top-down macroeconomic framework to project the US economy under different technical and resource assumptions. We separate the GDP contribution of shale gas from the one of light tight oil. We then relate their respective contribution to their interaction with the different energy markets and the rest of the economy. The detailed technical representation of the energy system in the Imaclim-R mode enables us to look beyond GDP at the structural mechanisms linking the energy component of growth on one side, and competitiveness and employment on the other side, driven by political choices regarding globalization. The direct economical impact of oil and shale gas can be marginal. But understanding the interplay of a bottom-up energy representation and the macroeconomy (Ghersi and Hourcade, 2006) may reveals general circumstances under which finer mechanisms could become the source of political tensions.

We found a direct positive impact on GDP growth despite a real exchange rate ap-

[3] Job creation in US manufacturing sector due to shale gas (PricewaterhouseCoopers, 2012) is not enough to offset the 33% drop of employment between 2000 and 2011 (Baily and Bosworth, 2014, fig. 2), which concerns 5 million jobs.

preciation induced by the resource boom in the US [4]. Beyond those GDP gains hides two side effects within the structure of the economy. The first one is lock-ins slowing down GDP improvements because of more fossil fuel intensive pathways and technical inertias on resource production. Secondly, a lower development of the US industrial sector follows the improving terms of trade. In a second set of scenarios, we look at a political strategy for the US to turn lower energy prices into sustainable long-term competitiveness increases for energy intensive industries. General equilibrium mechanisms shows that a strategy to support the US competitiveness and industrial exportations is at the expense of an alleviation of the positive effect on GDP and employment.

The paper is as follow. The next section 2 describe how oil and gas markets are integrated into the Imaclim-R framework. Section 3 study the positive impact of shale gas and light tight oil production on the US GDP, as well as the underlying fossil fuel insensitivity of respective pathways. We then study the impact of a political strategy supporting competitiveness of energy intensive industries in section 4. Section 5 concludes.

2 Methodology : hybrid modeling of oil and gas market in to the Imaclim-R general equilibrium model

Imaclim-R World is a recursive dynamic, multi-region and multi-sector hybrid CGE model (Waisman et al., 2012a). The consistency between the technical scenarios and the economic trajectory is insured by the integration of bottom-up modules with explicit technology into a top-down CGE macroeconomic framework. Annual general equilibrium (see fig. 6) determines relative prices, physical outputs, demand and the amount of savings consistently with short-term constraints, represented by fixed intermediate inputs and labor intensity, and decreasing marginal returns for labor per units of installed productive capital (Corrado and Mattey, 1997). Based on those economic signals with myopic foresight on their future evolution, the dynamic bottom-up modules (fig 7) determines investments into the next technological generation of capital for each sector. Capital accumulates with inertia with a putty-clay representation (Kehoe and Atkeson, 1999) so that only the new vintage comes to move the technical frontier with updated input-output coefficients and labor intensity (Ghersi and Hourcade, 2006).

The general architecture of Imaclim-R world has been described extensively in Waisman et al. (2012a). The set of equations of the core static general equilibrium is described in the supplementary materials of Waisman et al. (2012a). A detailed description of each bottom-up module can be found in Bibas et al. (2015). In the following sections we describe the specificity of the bottom-up modules driving oil and gas markets. The general rule is as follow. Each module determines regional investments in production units according to demand and future market share expectations, computed based on last years equilibrium value.

$$p_k = \sum_j pIC_{j,k} \cdot IC_{j,k} + \cdot l_{gas,k} \cdot (1 + tax^w_{gas,k}) + \pi_{gas,k} \cdot p_{k,gas} \left(\Omega_k \left(\frac{Q_{gas,k}}{Cap_{gas,k}} \right) \right) \quad (1)$$

[4] Magud and Sosa (2010) reviewed the literature on the resource curse phenomena and found no empirical nor theoretical evidence of direct negative impact on economic growth from a real exchange rate appreciation induced by a resource boom.

The new productive units add up to the in place capital stock Cap which is fixed in the static equilibrium. Next annual equilibriums then determines prices that clear markets, Ω being and increasing function of the payload of productive units Q/Cap, with Q the production level (equ. 1). Prices equilibrium are also directed by a fixed markup π. Depending on price signals and the demand of the previous equilibrium, each regional firm set the average level of its selling prices π in order to cover the increasing costs of extracting reserves, to which a scarcity rent is added depending on each region k market power. The other component of the price are intermediate consumptions $pICIC$, labor intensity l and wages w.

2.1 The oil bottom-up module

We model seven categories of conventional and five categories of non-conventional oil resources for each region. An oil category (i) is an amount of recoverable resources [5] associated to a threshold selling price above which investments in production units are made. This threshold serves as a proxy for production costs and accessibility [6].

Investments can be made in each oil category with a maximum growth rate ΔCap_{max}, representing geological constraints (inertias in the exploration process and depletion effects). The maximum rate of increase of production capacity for an oil category follow a bell-shaped profile, depending on the endogenous remaining amount of oil in the field. The function describing this maximum growth rate is calibrated on Rehrl and Friedrich (2006) [7].

Given the geological constraint, the production capacity at date t is given by the sum over all oil categories and regions. Non-Middle-East producers are seen as 'fatalistic producers' who do not act strategically on oil markets. Each time an oil category is profitable, they invest in new production capacity given the specific constraint described above. Middle-Eastern producers are 'swing producers', meaning they adjust their production level to apply their market power due to their low costs of production and fluctuation in the rest of the world conventional discovery (Gülen, 1996). As long as they have not reached depletion, they strategically determine their level of investments in order to control oil prices through the payload of their production capacities (Kaufmann et al., 2004).

They can in particular decide to slow the development of production capacities below the maximum rate in order to adjust the oil price according to their rent-seeking objectives. The dynamic behavior of this model has been fully studied in Waisman et al. (2012b) and Waisman et al. (2013) through two polar strategies of the OPEC : in the *limited development* strategy, investment are made so that to maintain medium-term prices around 80$/*bbl*, when in the *market flooding* strategy, higher investments aim at bringing the oil price back to pre-2004 levels (50$/*bbl*) and eliminate competitors.

Due to the high uncertainty on light tight oil resources, their production profile are only partially endogenous in our scenarios. We use projection of Energy Department (2015) for the US, IEA (2014) for other regions, reserves estimates from McGlade (2012)

[5] Total resource of a given category is the sum of resources extracted before 2001 and recoverable resources.

[6] Table 4 gives our numerical assumptions on the amount of ultimate resources in the main groups of regions. The figures are consistent with conservative estimates (USGS, 2000; Greene et al., 2006; Rogner, 1997), shale oil excluded.

[7] Rehrl and Friedrich (2006) combines the analyzes of discovery processes (Uhler, 1976) and of the "mineral economy" of (Reynolds, 1999) to model oil production with endogenous bell-shaped profile. .

and breakeven prices from Webster (2014). Investment in production capacities are frozen if the oil price drop below a threshold, moving the shape of production profile over time accordingly to remaining reserves. The production profile of the scenarios are shown in figure 13.

2.2 The gas bottom-up module

This section describes how dynamic of production of shale and other unconventional gas resources are implemented in the "gas supply" module of the Imaclim-R model. We build cumulative gas availability curve, based on BGR (2009) for conventional gas reserves and resources, McGlade et al. (2013b) for unconventional resources (shale gas, tight gas, and coal bed methane) [8], Aguilera et al. (2009) for conventional fields costs of production and ESTAP (2010) for relative costs between conventional and unconventional gas from ESTAP (2010).

As the conventional gas resource depletes across regions, production costs rises in the simulations from 0.5 $/GJ to 6 $/GJ. Due to the multiple uncertainty on the shale gas resource estimates (McGlade et al., 2013a), we use a unique 3.8 $/GJ threshold price for shale gas ESTAP (2010), which correspond to the breakeven price of actual producing sweet spots in the US [9]. Gas hydrates are not considered as a resource, as no mature technology already exists (Boswell and Collett, 2011). Table 1 summarizes resources and reserves amounts for the twelve regions, when figure 1 shows regional cumulative conventional gas availability curves.

Investment are made in each region based on expectations on future global demand (as guessed from past values of the simulation). Each regions compete on the international market taking into account their respective reserves availability and the payload Q/Cap of production capacities, the later serving as a proxy of relative profitability and competitiveness. The logit function describing regional market share in equation 2 is calibrated on outputs from the bottom-up POLES energy model (LEPII-EPE and ENERDATA s.a.s., 2009) to that to reflect historical production level. Reserves availability is the main driver of market shares ahead of payload of production capacities ($\gamma_{charge} < \gamma_{Res}$).

The regional dynamic of exploration and production among the different resources categories is as follow. Each year, reserves are depleted from the past year production, and resources are moved to reserve according to a reserves-to-production ratio calibrated at the base year reflecting a depletion/discovery process [10]. Once profitable, all shale gas resources are considered as reserves, because of the continuity of the source rock of shale fields. Within a region, shale gas production on one side, and conventional gas (mixed with tight gas and coal bed methane) production on the other side, are splited regarding their respective amounts of reserves and extraction costs.

[8] McGlade et al. (2013b) offers low, medium and high resource estimates for shale gas based on best estimates from an extensive literature review, which allow for consistent sensitivity analysis.

[9] Sweet spots are wells with the most producing rates. The shale gas resource being a continuous resource among a large scale source rock, sweet spots are concentrated in continuous area and can then be located. Less productive area should results in higher breakeven prices except for technological progress. Moreover, the US shale gas profitability may vary across basin, and condensates associated with gas (called wet gas) in some field raises profitability. See Paltsev et al. (2011) for scenarios in the US with sweet spots depletion and rising production costs, and Hilaire et al. (2015) for a discussion on the decreasing profitability along shale gas play.

[10] When there is three times less resource than reserve in a region, the R/P ratios is decreased by 6.7% by year, which is the observed value for Middle East since 2000 (British Petroleum Company, 2014).

Productive capacities are depreciated each year, with a 7% discount rate for conventional gas (corresponding to decline rates observed on production gas fields (IEA, 2009, table 11.8)), and a 50% decline rate in shale gas production (Hughes, 2013) modelling the sharp decline of wells production rate past the first year. This dynamic representation ensure consistency with gas production projection of Energy Department (2015); IEA (2015) (see fig. 12).

Between two period, the gas mean gas price evolves through the update of the markup π (eq. 1) reflecting increasing production costs and a scarcity rent. As long as oil prices remain below a 100\$/bbl threshold [11] , conventional gas prices follow oil markets with a 0.68 elasticity as calibrated on the World Energy Model (IEA, 2007) [12]. Above this threshold, regional gas prices are driven by increasing conventional production costs and a scarcity rent elastic to global demand. Shale gas only follow production costs, due to the specificity of its production economic and dynamic [13]. Short-term prices adjustment are made within the static equilibrium to clear markets depending on the payload of production capacities (eq. 1).

$$\Delta Cap_k^{gas} = \frac{(Res_k^{gas})^{\gamma_{Res}} (charge_k^{gas})^{\gamma_{charge}}}{\sum_k (Res_k^{gas})^{\gamma_{Res}} (charge_k^{gas})^{\gamma_{charge}}} \cdot \Delta Cap_{required,global}^{gas} \qquad \gamma_{charge} < \gamma_{Res} \tag{2}$$

2.3 Scenarios

We run four scenarios. The first one (i) is a reference without shale gas production in the US. In the second one (ii), the US produces only shale gas. In the third one (iii), the US produces only ligh tight oil. In the fourth one (iv), the US produces both shale gas and light tight oil.

In order to reflect the OPEC behavior regarding light tight oil production in the US, which is to maintain an increasing flow of oil production, we endogenously change the OPEC strategy from the *limited development* to the *market flooding* one when the US produces light tight oil [14].

In the section assessing policy aiming at supporting energy intensive industries competitiveness (sec. 4), we run a last scenarios similar to the fourth one but with an additional monetary policy controlling the real exchange rate appreciation.

[11] This threshold value reflects several aspects of oil and gas markets and links between the two commodities: strong substitution exists between the too commodities (Asche et al., 2012); nearly half of traded gas is price indexed on oil price in long-term contract (IEA, 2013, fig. 3.10); a declining part of gas is a co-product of oil production (called associated-gas (IEA, 2009, fig. 11.17)) or gas fields include gas condensate which are sold at oil prices (called wet gas); they also share drilling rigs as a common production need.

[12] This value is a mean of the econometric literature : with different, (Brown and Yücel, 2008) found a 0.14 long-term gas price elasticity to oil price, when (Asche et al., 2012) are closer to perfect substitute with a 0.924 value.

[13] This reflects medium-term price shocks due to the shale gas production dynamics, which may be produced regardless of the demand due to the short leasing activities periods in US (Hughes, 2013) and the sharp decline in the production rate at the well scale which ensure a fast drilling activity and strictly increasing production at a field scale (Kaiser, 2012; Gray et al., 2007) .

[14] The model exhibit long-term trajectory of energy prices. As a consequence, oil prices in simulations does not exhibit the recent fall observed in markets, reflecting more short term mechanisms. However, world oil price in the model exhibits a slower growth rate in the medium term with light tight oil production, as shown in figure 8.

Region	Conventional reserves	Conventional resources	Tight	CBM	Shale low	Shale medium	Shale high
USA	12.72	37.9	11.8	4	13.8	19.3	47.4
Canada	2.29	14.37	10.5	2.3	3.6	12	28.3
Europe	9.78	13.45	1.2	1.5	4.88	15.9	30.85
OECD Pacific	3.12	2.54	4.3	4.5	3.44	11.2	21.73
CIS	65.99	134.11	5.4	11.4	3.56	11.6	22.5
China	2.65	10.61	10.7	11.2	6.5	17.8	36.1
India	1.34	0.97	0	0.9	0.2	1.8	2.4
Brazil	0.38	2.14	0.35	0.04	1.96	6.4	12.42
Middle East	68.75	22.34	2.3	0	2.8	15.75	28.7
Africa	15.92	12.33	2.3	0.9	8.99	29.3	56.84
RoLA	18.31	23.41	2	2.2	1.3	11.7	22.1
Rest of Asia	9.28	14.77	3.35	0.36	13.16	40.6	75.95
Global	210.52	288.93	54.2	39.3	64.2	193.35	385.28

Table 1: Gas resource assumptions in Trillion cubic feet for 2001 (CIS : Commonwealth of Independent States; RoLA : Rest of Latin America). Adapted from BGR (2009) and McGlade et al. (2013b). As Brazil is not available in McGlade et al. (2013b), tight gas was taken based on the portion of conventional resource, CBM based on the portion of coal resources, and shale gas from EIA and ARI (2011).

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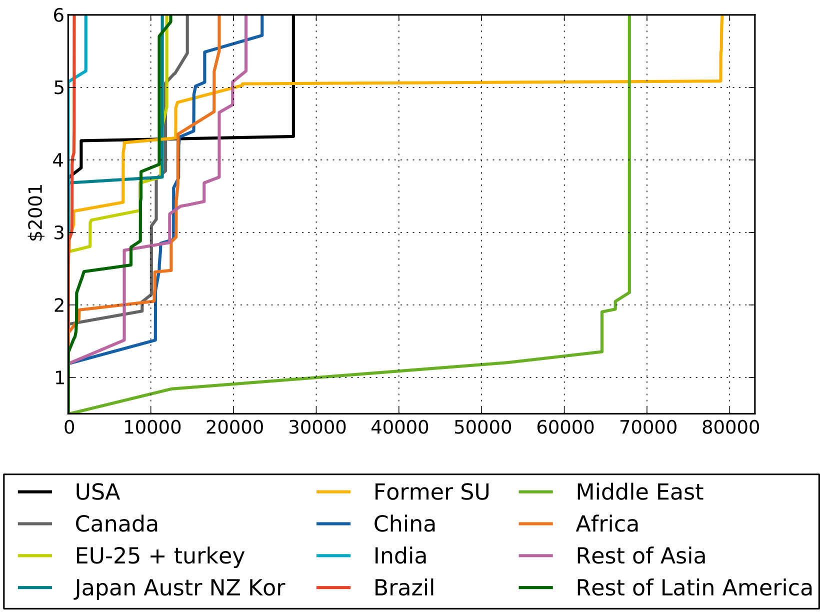


Figure 1: Cumulative availability curves for conventional gas (in Million ton oil equivalent per threshold of gas price). Resources have the same regional shapes.

3 The aggregate macroeconomic impacts and over time

This section examines the macroeconomic impact of continuous unconventional oil and gas production in the United States. It does so through four simulation scenarios : **(a)** In the reference scenario, we project the US economy as if it would have been in the absence of these resources ; **(b)** In a second scenario, US is assumed to produce shale gas, tight gas and coal bed methane ; **(c)** A third scenario considers the production of light tight oil only ; **(d)** The fourth scenario considers both shale gas and light tight oil production.

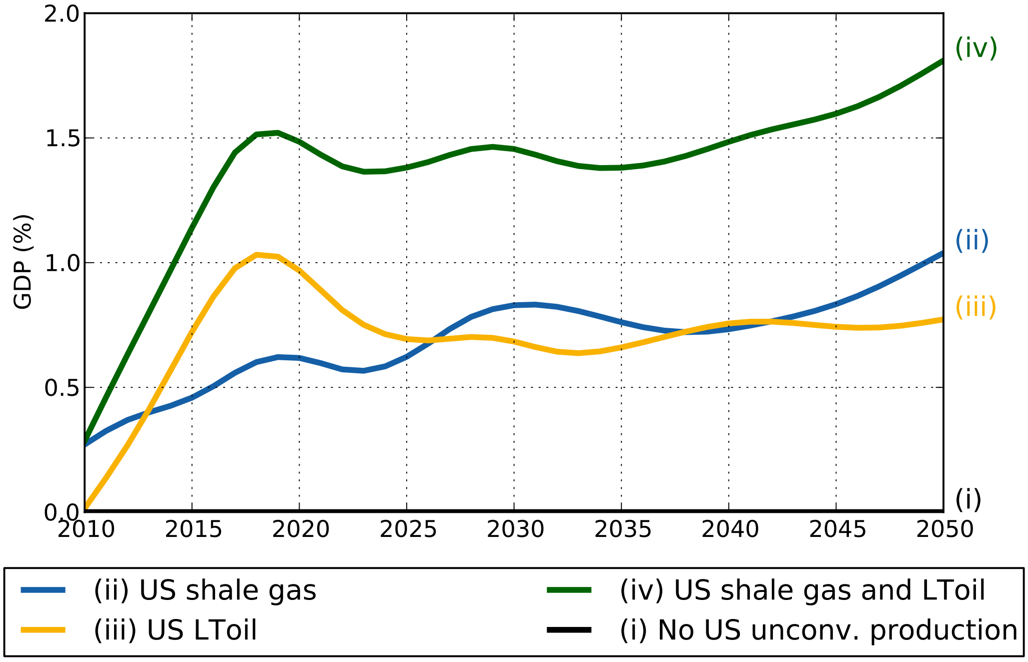


Figure 2: US real GDP (in PPP) - expressed in terms of percentage increase compare to the reference scenario (i).

Let us start with the variations of the GDP relatively to the reference scenario **(a)** [15]. Figure 2 show a GDP increase all over the period. GDP are increased in 2050 by 0.9%, 0.7% and 1.7%, respectively for the shale gas scenario **(b)**, the light tight oil scenario **(c)** and both combined **(d)**. In almost all scenarios except **(b)**, there is a relatively significant increase over two decades, then a plateau until 2050.

For the decomposition of those GDP increase, let us focus on the **(d)** scenario which aggregate both resource production. In this scenario, the value added of the energy

[15] This enables to catch slight differences in the GDP trajectory. Note that the figure is in relative terms. The US GDP is strictly increasing during the all period. In the figure, decreasing slops mean a slower growth rate of GDP, not a recession.

sector, which is account in 2050 for 5.4% of the US GDP, is increased by 11.8% in the scenario **(d)**. This results in a direct 0.6% increase of total GDP, a third of the 1.7% GDP gap of **(d)**. The rest lies in the variations of the three components of final demand. Despite a decrease of exportations, investments increases by 1% and households and public expenditures [16] , and a 0.2% decrease of exportations in 2050 for scenario **(d)** (figure 14, 15 and 16) by 1.9%.

If this global picture is in line with the to the conventional wisdom generally attributed to the discovery of a new source of energy, this is not the case of the behavior of the non-energy industries. We note indeed the paradoxical effect of a decrease of non-energy exportations. This contradicts the intuition of a positive effect of shale gas and light tight oil production on non-energy industries exportations. The mechanisms at play behind this paradox goes as follow. For the same trajectory in terms of trade deficit, the US can either preserve their competitiveness in non-energy goods by keeping stable the level of wages; the US can then import more of non-energy goods as employment raises [17]. They can alternatively increase their wages, which decrease their competitiveness and the surplus of non-energy goods. In both cases, the purchasing power of the US labor is increased. In the specification of our model, the assumption of wages elastic to the level of employment leads to a behavior between these two polar assumptions. However, the final outcome is an increase of wages, resulting into an increase of the production price despite a decrease of energy costs. Back to the figures, non-energy exportations decreases by more than 1.5% between 2015 and 2030, correlated with the increase of production costs relatively to world prices for energy intensive industries (+0.45%, fig. 17) and non-energy intensive ones (+1.1%, fig. 18). As those two sectors represents respectively in 2030 52% and 26% of exportations, this decrease more than offset the increase exportations in oil and gas (which account for a 0.3% increase of the total exportation value of the US in 2030).

Let us retain at this stage that despite less non-energy goods exportations, the US unemployment is reduced [18] , because the lesser share of non-energy goods production oriented towards exportation is over-compensated by the GDP growth. This results in higher wages in 2050 (0.5% for sc. **(d)**, fig. 19) and increased terms of trade for non energy sectors.

Before entering the discussion, let us start with the understanding of the indirect mechanisms beyond those positive effects on GDP. We provide below an overall picture of the separate mechanisms at play for shale gas and light tight oil production, and conclude on the combine effect of the two resources production.

The shale gas specific effect (c) : The impact of shale gas production on the US GDP can be divided in three different periods.

(1) During a **first period** (2010-2030), shale gas production boosts the economy through **two main channels**.

The first channel consist in the stimulation of domestic markets through higher purchasing power of households for non-energy goods. This is consistent with higher wages

[16] In the model, public expenditure are indexed as a constant proportion of GDP.

[17] Obviously, this mechanism is true at the aggregate level, but encompass distinguish behaviors for the different sectors. We come to that in section 4.

[18] Employment increases by 4% by 2020 in the scenario **(d)** with shale gas and light tight oil production (see fig. **??**). Thiemo Fetzer (2014) found similar results (0.406% in 2012) with spatial econometrics on real datas.

due to lower unemployment and lower energy prices. Lower gas production costs (8% lower in 2030) decrease electricity prices (3% in 2030) thanks to substitution from coal to gas in the power sector (50% more of gas, 15% less of coal in 2030). Liquid fuel prices are also lower (-0.13%) as the impact of US shale gas on global markets results in a lower world demand for liquid fuels [19]. Those lower energy prices allows for a reduction of households energy bill (3.2% in 2030), mainly through the diminution of the costs of residential heating and the cost of private transportation.

The second channel is the increase of the drilling activity and industrial margins. Lower energy prices leads to a drop in the energy component of production costs for industries using electricity or gas as feedstock (the total costs of production is 0.6% lower in 2030). In relative terms, the share of the value added over total production costs increases. The decrease of energy costs do decrease total production costs, but part of the surplus can be captured by industries in the value added, especially in the context of increasing final demand. Part of the raise of the value added is capture by the workers through higher wages, but a significant remaining part results in terms of higher margins [20]. This allows for more expense in investment from industries and then reinforces the total activity.

(2) During the **second period** ($2030 - 2040$), the same mechanisms are at play. But GDP gains are stopped because of the marginal increase of liquid fuel dependency in private transportation amplifying the consequences of Middle East oil resources depletion. At the margin in our scenario, more use of gas than fuel in residential heating systems and redirected investments towards gas intensive industries results in a marginal decrease of total liquid fuels demand (-0.17%) and prices (-0.13%). But households usage of private fuel intensive transportation (air travels, personal cars) increases because of higher wages and purchasing power induced by the reduced energy bill. The US consumption style regarding private transportation is then more fuel-intensive in 2030, when Middle East oil production start to decline and world production take the shape of a long plateau (see fig. 9), as described in Waisman et al. (2012b). The very structure of the Imaclim-R model results in a supply shortage around its highest level of production, because of the time required for new fields and oil categories in the world to deploy production. The mismatch between an increasing world demand and the technical inertias of oil industries generates higher oil prices [21]. This general context of tense oil markets on one side, and the marginal increase in the demand of liquid fuel for private transportation induced by shale gas development on the other side, constraints one of the key mechanisms observed in the first period, namely the purchasing power increase in non energy goods allowed by lower energy bills. It also impact production costs of industries, reducing their margins and investment attractiveness.

[19] The availability of shale gas in the US also reduces tensions on all fossil fuel markets : the unanticipated substitution from coal to gas in the US power sector results in coal exportations of the surplus of production ; gas not imported from the US (cf. production capacities recently built in specifically in Qatar, now sold on the European spot market) is available for other regions. Then the same mechanisms are at play worldwide : more availability of coal and gas and induces substitutions and results in a lower aggregate demand for fuel. A direct effect is to delay and smooth over time the deployment of most expensive oil fields.

[20] This is possible as the model implicitly assumes an oligopolistic markets through the specific markup pricing representation.

[21] Obviously biofuels and coal-to liquid comes to offer a substitute on liquid fuel markets, but higher production costs and time-to-build facilities results in productivity losses and a reduced activity for fuel-intensive industries.

(3) Our results are consistent with the Energy Modeling Forum (2013) model comparison exercise, which stated that shale gas in the US is likely to delay the energy transition towards low-carbon futures. But in our simulations after the $2030-2040$ decade the rise of energy prices reverses the mechanism at play and alleviates those lock-ins [22]. The increasing production of gas boosts again the economy. Despite the beginning of shale resource depletion in the US (2045 in our scenarios), the long-term effect of more resource availability and its impact on fossil fuel markets continue to have a positive effect on the US GDP (up to 0.9% in 2050).

The light tight oil specific effect (c) : The overall same mechanisms are at play for light tight oil production. But relative different strengths of those mechanisms leads to distinct time profiles.
(1) Within the first five year of production (2010-2017), GDP rise steeply by 0.9% because of the oil price drop. In the model, the gap between the demand and the sudden upcoming new oil production capacities results in lower short-term world oil prices. As a response to the resurgence of the US in the market, we endogenously change Middle East's behavior towards sustained flowing investment in oil production capacities, so that oil prices have different paths accross scenarios (fig. 8). Obviously the model can not incorporate the geopolitical determinant of the current oil price (50% drop in the second part of 2014). However, the *market flooding* strategy, as a tradeoff between short-term costs and long-term benefits, represents one of the possible rational of Middle East behavior, as demonstrated in (Waisman et al., 2012b). Consequently with US light tight oil production, like in the case of shale gas, households purchasing power for non energy good raises because of higher wages and cheaper oil prices reducing the energy bill (6.6% in 2017). This stimulate domestic markets, which triggers higher investments along with reduced margins through lower energy production costs for industries.
(2) During a second phase (2017-2030), oil prices adjust to its new long-run path, as the *market flooding* strategy of Middle East has a limited effect when approaching their peak of production, so that past 2020 the effect on world oil price is reduced. This blocks one of the virtuous mechanism, namely the reduction of the energy bill, generated by light tight oil production. Another differences between the shale gas scenario is that past 2020, the light tight oil production of the US start to decline, so that the relative decrease of energy imports between scenarios tends to be reduced. More expensive imported oil reduces the positive effect on the US energy bill.
(3) During the 2030-2040 world *plateau oil* transition period, the US benefits from Middle East resource depletion to gain slight market shares in the oil markets (figure 9). Furthermore, the US light tight oil revolution postponed past 2040 the deployment of most expensive world oil categories and fields, benefiting all oil dependent economy from long-term GDP gains, so that the GDP increase remains at 0.7% in 2050.

The shale gas and light tight oil combined effect (d) : The combined effect of shale gas and light tight oil production leads to a GDP increase (around 1.6% in 2050) similar to the sum of the two separate mechanisms. When we aggregate the two curves,

[22] On the supply side, as energy prices rises, biofuels and coal-to-liquid comes substitute to refined oil. On the demand side, the emergence of electric vehicles helps the private transportation sectors to face the transition. As shale gas production reduces in the medium-term the overall demand for fuel globally and in the US, the emergence of biofuels and coal-to-liquids production capacities, and technological progress in electric vehicles are delayed.

we still find the three major phases corresponding to different levels of the virtuous mechanisms described. In $(2010 - 2020)$ the sharp increase of GDP gains is mostly motivated by oil. During $(2020-2040)$ shale gas continue to boosts the economy, while the effect of oil start to be alleviated because of depletion. The depletion of Middle East resources starting from 2030 alleviates both resources effects for different reasons : the effect of US light tight oil production on oil prices is limited to the ability of the OPEC to respond strategically ; the marginal higher dependency on liquid fuels generated earlier by shale gas production increases GDP losses due to oil shortages. Finally, from 2040, GDP differences are maintained and increases because of the long-term effect of fossil fuel resources availability induced by unconventional production in the US.

Compared with other studies, we found slightly more positive effect of unconventional resource production than the simulation of (Hunt et al., 2015) (1.5%) and the estimation of Spencer et al. (2014) (0.84%) considering shale gas only. One of the major different determinant is the way we implicitly model the OPEC change of strategy as the US produces light tight oil. Our results tend to become similar to those of (Hunt et al., 2015) when relaxing the constraint on constant current account per GDP units, as done is the next sections when looking at competitiveness oriented policies facing the unconventional boom.

4 The US competitiveness and globalization

The way which lower energy prices impacts the US industrial competitiveness is not unequivocal. It depends on how the benefits of this new resource are distributed among the economy. The US faces a range of strategical alternatives to manage this manna from heaven, which fits within two polar strategies : (i) in the first one, which correspond to the previous section, the external current account is kept to a percentage of GDP, and the money is neutral. The exchange rate between the US dollar and other currencies follow the appreciation of the terms of trade, whose benefits are captured by households; (ii) In the second, the US government tries to improve the trade balance by favoring exporting industries. It does so by keeping the real exchange rate unchanged by comparison with the reference scenario through an active monetary policy.

$$TradeBalance = Exp - e * Imp = e * Imp_K - Exp_K = \alpha * GDP \tag{3}$$

Actually, the current account and the real exchange rate movements are complementary, and most likely the variations of the later are driven by the policy regarding debt. In modelling terms, the two polar strategies can be translated through different so called closure rules, given the constraint of respecting the Walras law. In the first case, the current account is set to a percentage of the GDP and the terms of trade changes endogenously together with the exchange rate of the dollar. In the second, the nominal exchange rate is fixed, letting both the terms of trade and the current account being endogenously determined.

Let first denote e the factor of distortion between the terms of trade and the exchange rate. If e is kept constant and equal to 1, a 10% variation of the terms of trade leads to the same percentage of variation of the exchange rate of the dollar. In other terms, the money is transparent, and their is no active monetary policy.

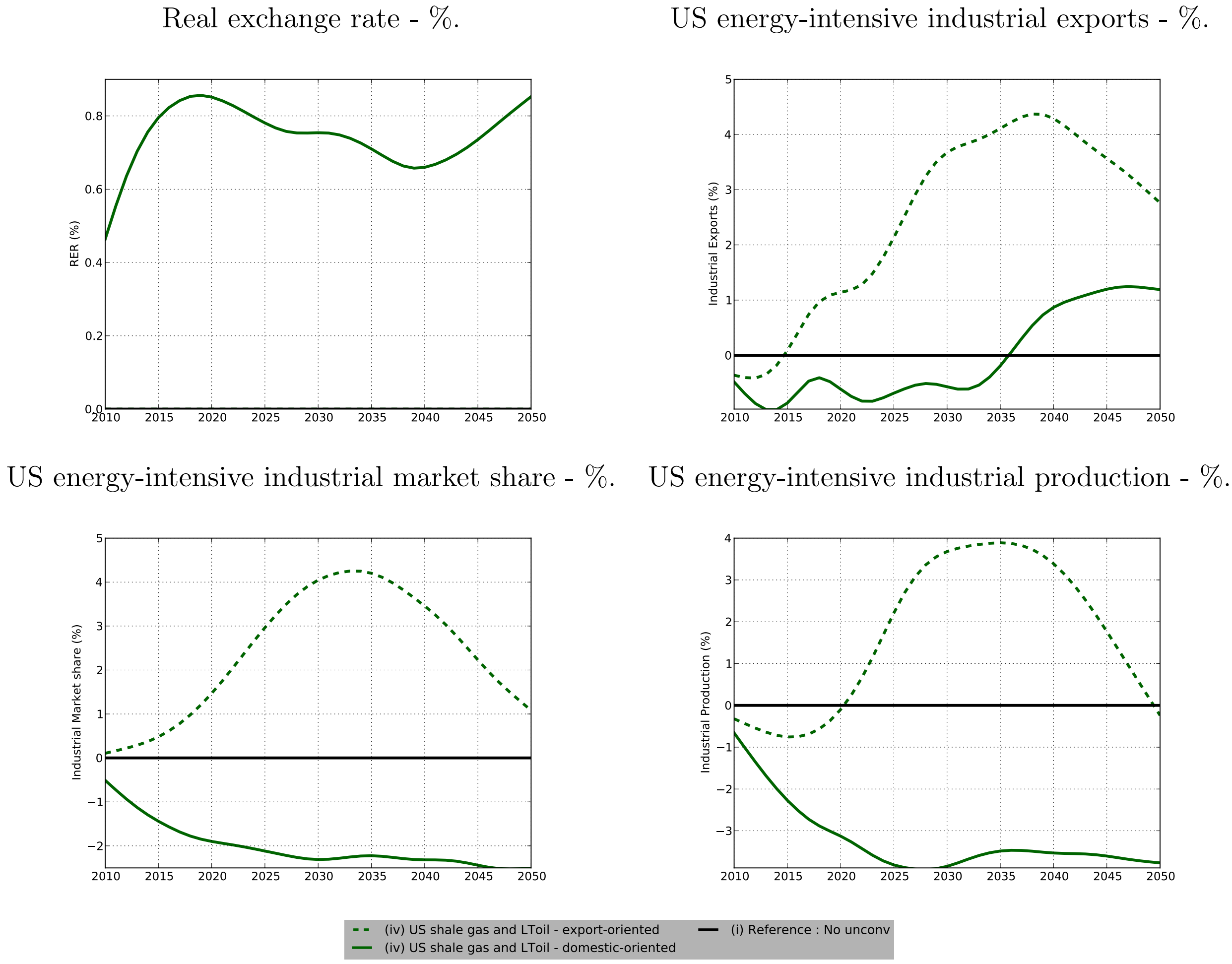


Figure 3: Real exchange rate, energy intensive industrial production, exports and market share of the US economy, relatively to the reference scenario without shale gas or light tight oil production. Plain lines represent the base case with constraint capital movements. Dotted lines simulates a policy to maintain exchange rate at the reference scenario with no resource production.

We now consider, as in the previous section, a trade balance (TB) and a deficit driven by the GDP evolution, as described in eq. 3 [23]. Due to the order of magnitude by which energy imports shrinks because of unconventional resource production, the current account constraint implies a corresponding decrease of exports and increase of imports. As a consequence the model computes higher wages which allow to respect the current account constraint. In this very specific case, unconventional oil and gas resource production allows for higher wages supported by better terms of trade (TOT) (-1.45% in 2030, see table 2) [24]. Ultimately, lower energy prices are turned into higher production costs

[23] The Trade Balance (TB) is expressed as the differences between the value of exports Exp and the value of imports Imp expressed in the domestic currency. His complementary, the net imports of capital flows $e * Imp_K - Exp_K$, is a fraction α of GDP.

[24] The terms of trade (TOT) are expressed by relative value of exports to imports. Lower terms of trade means than less exports are required to buy the desired amount of imports : the effort the economy makes to benefits from international trade can be eased off. The raise of nominal wages is here supported by better terms of trade, driven by the energy imports shrink.

relatively to world prices (fig. 17 18). Raising wages decrease the US competitiveness of the US non energy industries and so the total value of exports (−2.1%, see table 2) despite the raise in energy exports. Similarly, we observe an increase of US imports of non-energy goods (+12.3% for energy intensive goods). At the aggregate, the increase of wages and the terms of trade improvements (−1.45%) are consistent with the trade balance movements (−1.97%) following GDP variations (+1.4% in real terms).

When the trade balance is constrained, the resource production surplus is translated into an increased purchasing power of households with a side effect on exports. The mechanism at play is the one behind the so called *dutch disease* effect. In the theoretical paper of Corden and Neary (1982), the relative increase in energy net exports constraints other exports, especially if short-term capital movements across sectors is constraint. As resources (labor and investment) are in the short-run reallocated towards the booming energy sector, improvements in energy trade balances squeeze other tradable sectors (Neary, 1985). Beyond this apparent competitiveness paradox (improved terms of trade but a decrease of non-energy intensive exports despite lower energy costs) lies the misleading view of a nation competing on international markets as industries does. This confusion was highlighted by Krugman (1994): whereas an industry exposed to international markets may go bankrupt if not selling enough, the trade deficit of a nation may, depending of the circumstance, be associated with increasing wealth.

To fulfill the reasoning, one still have to explain why the nominal wages increase is the mechanism through which the current account is kept at the same balance. As incomes raise with job creations, US households captures the benefits of the terms of trade improvement. On one hand, the domestic demand for non-energy intensive goods raises despite the evolution of preferences towards imports. US households' marginal utility is higher for non-energy intensive goods, with a 72.9% share of total consumption in 2030 among which only 2% are imported : a raise of income results in a domestic demand increase [25]. On the other hand, the energy-intensive industries activity, exposed to foreign market competition (15% of total production is exported at the base year), shrinks because of a loss of competitiveness. This helps to keep the current account at the same balance despite the reduction of energy imports. In terms of employment, the loss of jobs in non-energy intensive industries is more than offset by those created in energy intensive industries [26], due to the differences in labor intensity of those two aggregated sectors. The increase of the demand for domestic goods reinforce the total activity, which helps to reduce unemployment. The resulting nominal wages revaluation, driving the real exchange rate appreciation, is then consistent with the improvement of the terms of trade, the current account policy and the GDP improvements.

Let us now consider the case of a monetary policy aiming at supporting exports and industrial competitiveness. The US government can, if it wishes, reduce the supply of money and prevent the appreciation of the real exchange rate due to the use of shale gas. Such a strategy would come from pressure exerted by the lobby of highly exporting com-

[25] Preferences between domestic and imported goods in the model are represented through Armington specifications. When income raise, the demand for non-energy intensive goods of the US households increase. As the terms of change improves, the imported share of this demand also increase. In general, the income elasticity of the first is greater than the price elasticity of the later.

[26] In 2025, gross employment increase by 2.6 million units, among which +9% comes from the oil and gas sectors, −36% from energy intensive industries, and +45% from of non-energy intensive industries.

	ref/2001	Shale/ref	Shale+MP/ref
TOT (Terms of Trade)	3.64	-1.57	31.54
Trade Balance	-140.44	-2.25	85.67
Domestic labor devoted to imports (DLI)	83.5	-2.44	-25.18
Exports in value	169.04	-2.12	-0.03
Imports in value .wp	160.42	-0.91	-23.86
Exports in value (energy)	1236.66	7.16	7.48
Exports in value (other)	193.16	-4.59	-0.9
Imports in value (energy)	650.45	-37.46	-35.98
Imports in value (other)	89.3	9.96	-9.74
Exports in value (non energy intensive sec.)	293.56	-5.87	-5.1
Exports in value (energy intensive sec.)	103.03	-1.17	1.55
Imports in value (non energy intensive sec.)	480.12	18.33	6.86
Imports in value (energy intensive sec.)	61.35	13.75	-30.35

Table 2: Terms of trade indicators in relative terms (in %, for the year 2030). The first column (ref/2001) indicates the evolution of the reference scenario in 2030 compare to the base year 2001. The second column (Shale/ref) indicates the value of the shale gas scenario compare to the reference one in 2030. The third column (Shale+MP/ref) indicates the value of the shale gas scenario with the Monetary Policy compare to the reference one in 2030.

	Exports	Imports	wages costs
Non-energy itensive industries	24.33	16.29	16.86
Energy itensive industries	55.76	50.26	10.31
Energy	8.0	27.71	11.84
Other	11.91	5.74	60.99

Table 3: Exports and imports of all sectors as a share of total (%). Wage as a share of the production costs (2030). In this table, the sectors of Imaclim-R are dispatched into non-energy intenseive sectors, energy intensive ones, energy sectors and others.

panies or from the desire to improve the labour market in the corresponding sectors [27]. Within the model, we use as an approximation of the real exchange rate the value of the U.S. basket of goods relative to its value at the prices of the foreign good, as described in Equation 4. The monetary policy allows, by increasing the supply of local money, to stabilize the real exchange rate at its reference path value, that is, to devalue the U.S. dollar relative to this same path (Corden, 1981).

$$ExchangeRate_{Imaclim} = \frac{\sum_i (p_i * Demand_i)}{\sum_i (pImports_i * Demand_i)} \tag{4}$$

Despite the expected positive effects on industrial competitiveness, we see a decline in GDP compared to the previous scenario (without monetary policy). Figure 4 shows that this brings GDP back to a path close to the reference scenario (without shale gas and oil). This decline is correlated with a decline in aggregate demand, falling from +1.57% to -0.39% (tab. **??**). Looking at the other components of GDP for the year 2030 of the simulation, we see that investement movement are more or less correlated with movement of the trade balance.

Let us now look at the sectoral components of the improvement in the trade balance (from -2.25% to +85.7%) using Table 2 : Not surprisingly, the energy trade deficit is reduced (from -37.5% to -36.0% of imports, from +7.2% to +7.5% of exports). As expected, the monetary policy supports the competitiveness of energy-intensive industrial goods exports (from -1.17% to +1.55% in value). These industries recovered +3.0% of market shares in the global market and increased their export volume by 3.5%. There was also a significant decrease in imports of energy-intensive goods (from +13.8% to -30.4%). We also observe a relative increase in the competitiveness of non-energy intensive industrial goods (+18.3% to +6.9% of imports, -5.9% to -5.1% of exports). However, the net loss of competitiveness in this sector observed during the first scenario set is maintained. Finally, other sectors include agri-food and transport services. These are highly energy intensive and gain in competitiveness (from +10.0% to -9.7% of imports, from -4.6% to -0.9% of exports). These variations can be explained primarily by changes in the cost of production of each sector relative to the cost of production of the foreign good. The paradox that links an increase in industrial competitiveness with a deterioration in GDP is explained by two opposite effects of a fall in the domestic price relative to the import price. This undoubtedly strengthens the competitiveness of the domestic energy intensive industries. But this compensate the compression of household purchasing power in terms of imported goods.

$$DLI = \frac{e * Imp}{GDP} * TotalLaborForce \tag{5}$$

This negative effect can be understood from the evolution of an indicator, which we call the "domestic work dedicated to imports" (DLI), representing the labour force needed to generate the national income that pays for imports (eq 5). This indicator illustrates several mechanisms depending on the point of view chosen for comparison (over time, or between two scenarios for a given year). As we shall see, it appears as a reliable indicator of competitiveness at the macro-economic level: **(a)** First, consider a change in the DLI over time. Reasoning at a constant labor force L, an increase in the DLI indicates an increase in purchasing power in terms of imported goods. In our

[27] Baily and Bosworth (2014) shows the importance of the US manufacturing sector competitiveness in ensuring employment and trade balance stability.

reference trajectory without shale gas, the DLI increases in thirty years (+83.5%) due to technical progress. **(b)** Then consider the case of the scenario studied in the previous section, i-e with constant trade balance shale gas production. The DLI varies (-2.44%) with respect to the reference trajectory. If we take this indicator as the definition of global competitiveness, the later is improved slightly, despite the observed decline in industrial exports. **(c)** Finally, let us now return to our scenario of holding the real exchange rate appreciation at the reference case trajectory through monetary policy. Suppose that the nominal exchange rate changes captured by e (equation 5) accurately compensate for changes in the value of imports (for a given GDP/L which is the level of labour productivity). The same DLI is then necessary to buy imports, but the purchasing power in terms of imported goods of this albor force DLI, expressed in terms foreign currency (Imp/DLI) decreases. In this very precise example, constraining the real exchange rate to the one of the reference path make comparable the baskets of imported goods. The changes in the DLI therefore provide an additional information, namely the change in purchasing power in terms of imported goods relatively to the reference path. The DLI act as an indicator of the change in overall competitiveness (in the sens of a nation), understood as the labour needed for imports, as well as measuring how many overtime hours are needed to import the same basket of goods as in the reference case.

The simulations clearly show a decrease in the DLI (-25%, Table 2.1) with monetary intervention (-2.44% without policy). This reflects both an improvement in overall competitiveness, followed by an increase in industrial exports, and a decline of the purchasing power in terms of imported goods. To maintain a given level of imports, a larger share of households' income is required. The remaining share, allocated to the consumption of domestic goods, is then reduced, leading to a fall in aggregate demand. The gains in purchasing power due to the fall in energy prices are not enough to compensate for this loss in terms of imported goods.

In the model, wage dynamics are represented as a competitive economy. Part of the loss of purchasing power described above is recovered through wage bargaining. The evolution of wages in relation to the evolution of the price of the basket of goods will depend on the bargaining power of employees on the labour market. As the fall in aggregate demand associated with the loss of purchasing power leads to an increase in unemployment, workers will only recover part of their purchasing power, in the form of an increase in net wages. This decline in purchasing power reinforces the decline in aggregate demand associated with an increase in the level of imports.

Competitiveness is not evolving in the same way for all sectors. This is due to the different variations in the components of the cost of production. The effect of lower energy prices will dominate for energy-intensive and heavy industries. However, the labor cost increases for all sectors, resulting in higher production costs in non-energy intensive sectors. In the model, the labor cost is the result of three forces. The first two, which we have described above, are the two components of the loop linking unemployment and wages, namely the indexation of the nominal wage to price levels according to power relations, and the unemployment rate. These two components drive the wage cost down. But this drop in the wage cost induced by the wage-unemployment loop is more than offset by a third mechanism: the increase in the compensation per hour worked as a result of the investment dynamic.

The compensation per hour worked, within the model, will depend on the payload of the installed capital stock. The model captures the payload of the equipment stock (Berndt and Morrison, 1981; Corrado and Mattey, 1997), considering better paid over-

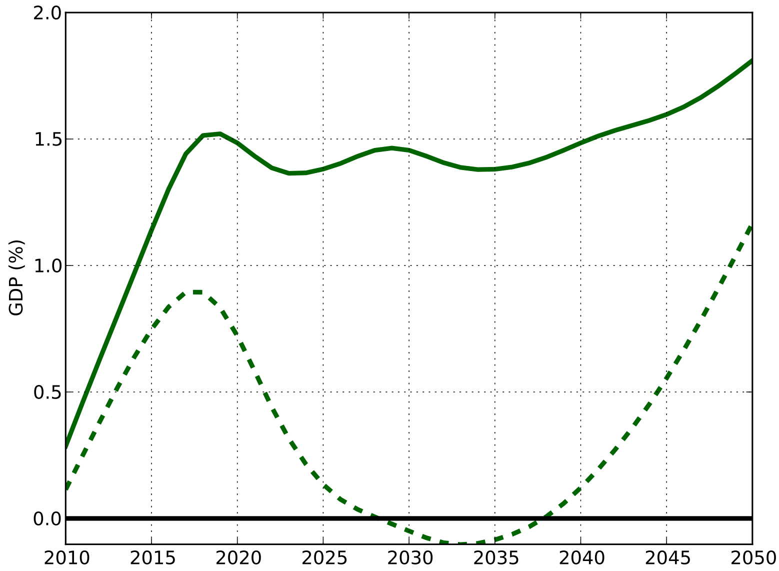


*Figure 4: US real GDP (PPP) with policy simulation (dashed line) - variations from scenario **(i)** (plain line, in %).*

time per full-time equivalent. As shown in Table 2.5, the capital stock payload increases both in the energy intensive industrial sector (+25.8%) and in the non-intensive sector (+13.7%). This last result may be surprising, as one would expect a drop in payload due to the drop in production. In reality, it is driven by investment dynamics are modified by the evolution of capital flows.

In accounting terms, at a given balance of payments trend, any change in the trade deficit is converted into capital flows. In this scenario where the trade balance improves, the associated reduction in capital inflows will modify the investment dynamic. This macroeconomic constraint of the model can be interpreted as the fact that a more lax monetary policy goes along with lower interest rates, which reduces the attractiveness of the US economy for foreign capital. There is therefore a strong investment constraint on industries, which pushes investment towards the most productive units, along with increasing payload of installed capacity. On the one hand, investment is directed towards export industries that are becoming more competitive, but on the other hand total investment is falling in all sectors. The increase in production is therefore satisfied by greater use of the stock of equipment in place. The associated workforce is then more flexible in terms of hourly volume, for example via shorter-term contracts (temporary work), with resulting increased unit labour costs.

5 Conclusion

We have shown in this article how the production of unconventional fossil fuel resource boost the US GDP. Shale gas alone contribute to a 0.9% relative increase in GDP in 2050, while light tight oil contribute to a 0.7%, and both resource lead to a 1.6% increase. Despite an increasing production level during all the period, GDP gains are alleviated

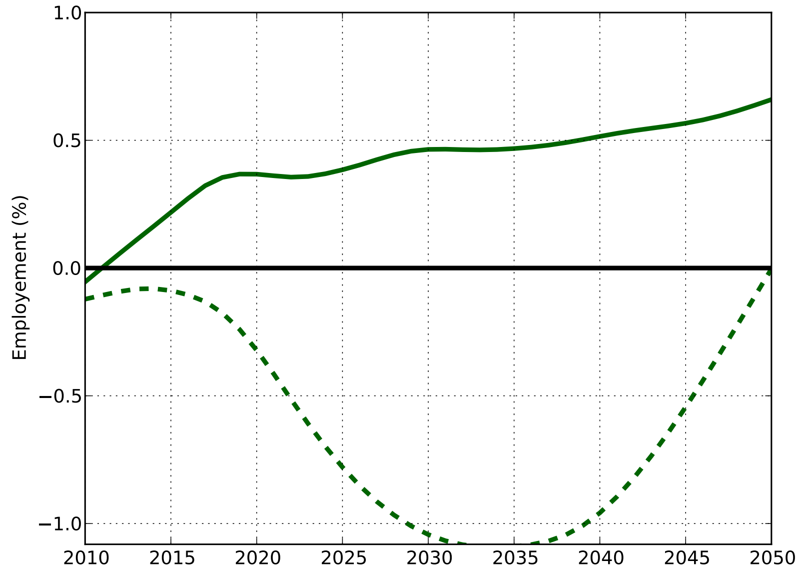


*Figure 5: Employment in the US with policy simulation (dashed line) - variations from scenario **(i)** (plain line, in %).*

within 20 years due to technical inertias. The greater availability of fossil resources goes along with an increased dependence on energy use in household consumption. When these resources become scarcer and prices rise, the extraction activity only compensates for the relative losses in GDP due to greater tensions on the energy markets.

Secondly, we saw the importance of distinguishing the notion of competitiveness of a nation from that of an industry. The US government can choose to turn lower energy prices into higher exports of energy intensive industries by controlling the exchange rate appreciation. Employment in these industries is then increased, to the detriment of GDP gains and total employment gains in the economy.

This work focuses on two issues related to large-scale fossil resource production. On the one hand, the energy sector boom must be accompanied by an overall energy policy in order to control the slackening of behaviour that could be goes along with. On the other hand, the resource curse mechanisms identified are linked to the context of globalized world : a policy aiming at transforming lower energy prices into gains in competitiveness for industrial exportations is ineffective in terms of global welfare. Following the definition of Krugman (1994), the overall competitiveness of the economy is improving in all cases. It is then necessary to find policies of accompaniment other than a raw form of protectionism, such as a different flexibility on the labour market, to mitigate the impacts on highly exporting industries.

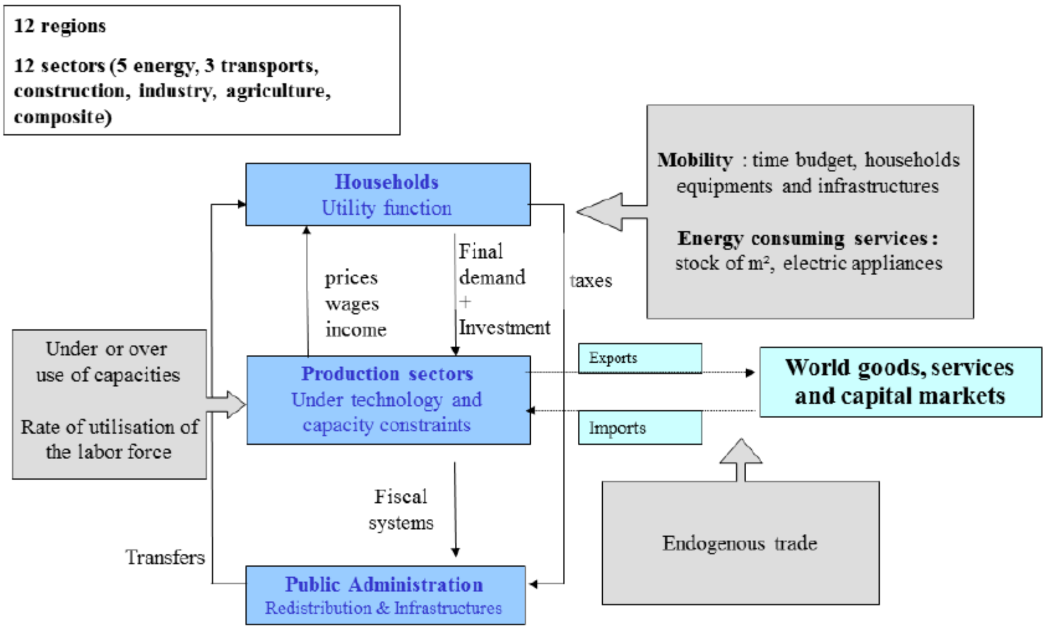


Figure 6: Static equilibrium of the Imaclim-R hybrid model

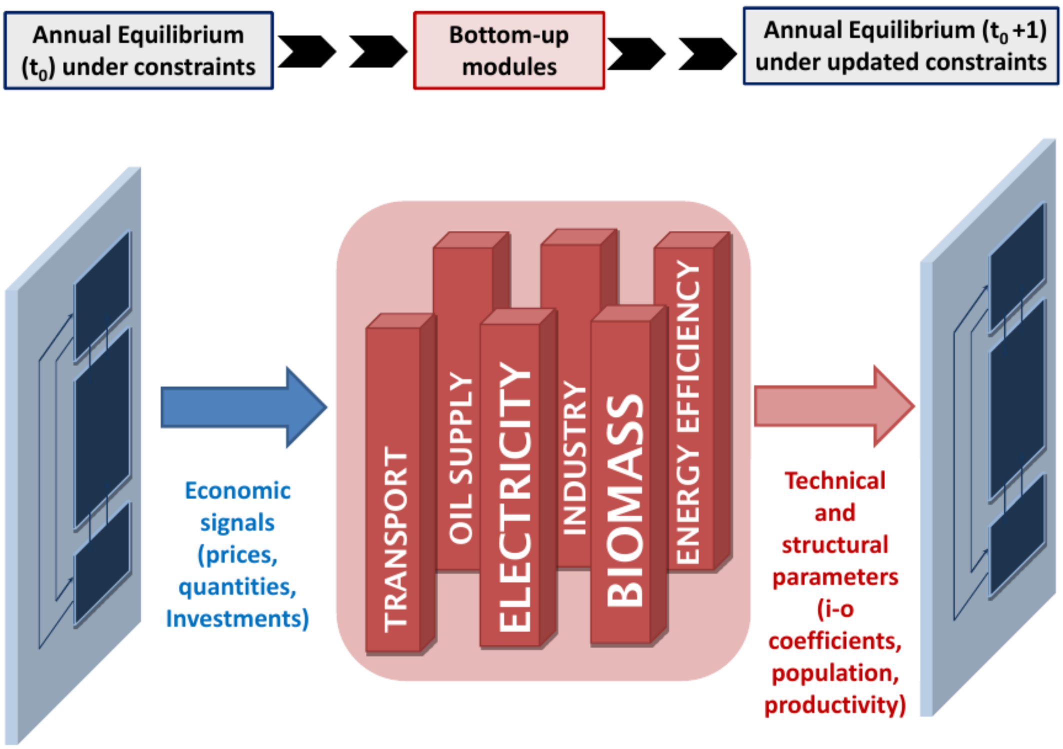


Figure 7: The recursive and modular architecture of the Imaclim-R hybrid model

3* Resources extracted before 2001	Recoverable resources beyond 2001*				
	Conventional oil		Non conventional oil (Heavy oil and Tar sands)		
	Middle-East	RoW	Canada	Lat. America	RoW
0.895	0.78	1.17	0.22	0.38	0.4

* "Recoverable resources" are 2P reserves (Proven + Probable) remaining in the soil, which has been identified as the relevant indicator to investigate global oil peak (Bentley et al., 2007).

Table 4: Assumptions about oil resources in the central case (Trillion bbl)

	Shale+PM/ref	TB contribution
Trade Balance (TB)	85.67	83.3
Exports in value (energy)	7.48	1.7
Exports in value (other)	-0.9	-0.28
Exports in value (non energy intensive industries)	-5.1	-3.5
Exports in value (energy intensive industries)	1.55	2.0
Imports in value (energy)	-35.98	-37.6
Imports in value (other)	-9.74	-1.77
Imports in value (non energy intensive industries)	6.86	4.6
Imports in value (energy intensive industries)	-30.35	-48.55

Table 5: Trade balance improvement decomposition (in %, 2030). The second column (Shale/ref) indicates the value of the shale gas scenario compare to the reference one in 2030.

	Shale/ref	Shale+PM/ref
GDP = D + I + (X-I)	1.49	0.04
Demand (D)	1.57	-0.39
Investment (I)	2.3	-17.79
Exports (X)	-2.12	-0.03
minus Imports (-I)	0.56	24.0

Table 6: GDP variation from an expenditure perspective (in %, 2030). The first column (Shale/ref) indicates the value of the shale gas scenario compare to the reference one in 2030. The second column (Shale+MP/ref) indicates the value of the shale gas scenario with the Monetary Policy compare to the reference one in 2030.

	Production Capacities	Production	Payloadcharge
Non energy intensive sectors	-14.51	-2.79	13.71
Energy intensive sector	-14.25	7.87	25.81

Table 7: Production capacity, production level and payload decomposition (2030) comparing the shale gas scenario with the monetary policy to the one without policy (in %).

	Ref	Shale	shale+PM
Investment / GDP	0.233	0.235	0.189
State Expense / GDP	0.11	0.107	0.108
Gross national product / GDP	0.562	0.568	0.279
Net capital inflows / GDP	0.386	0.392	0.103

Table 8: Investment, state expense and net capital inflows in terms of GDP, in 2030, for the three scenarios. The first (Ref) is the reference scenario (without shale gas production. The second column (Shale) is the shale gas scenario without monetary policy. The third column (Shale+MP) is the shale gas scenario with monetary policy.

Figure 8: World oil prices trajectory with and without light tight oil production in the US, in percent.

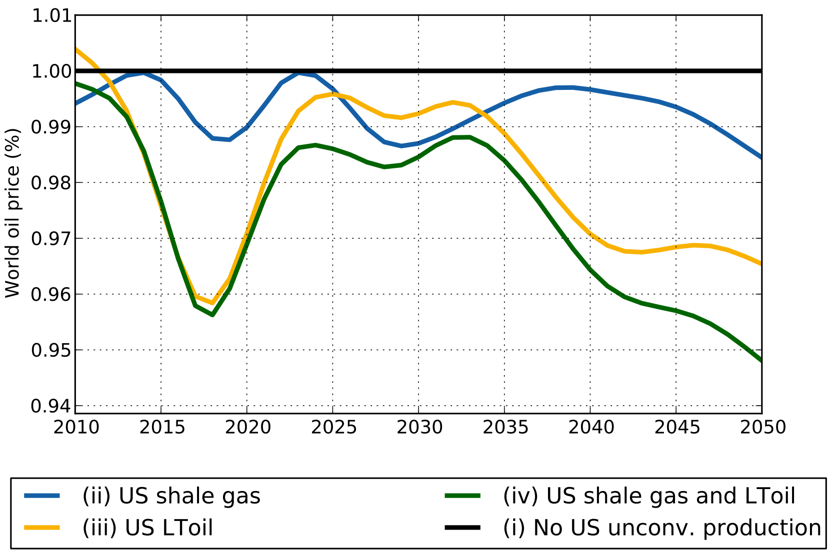
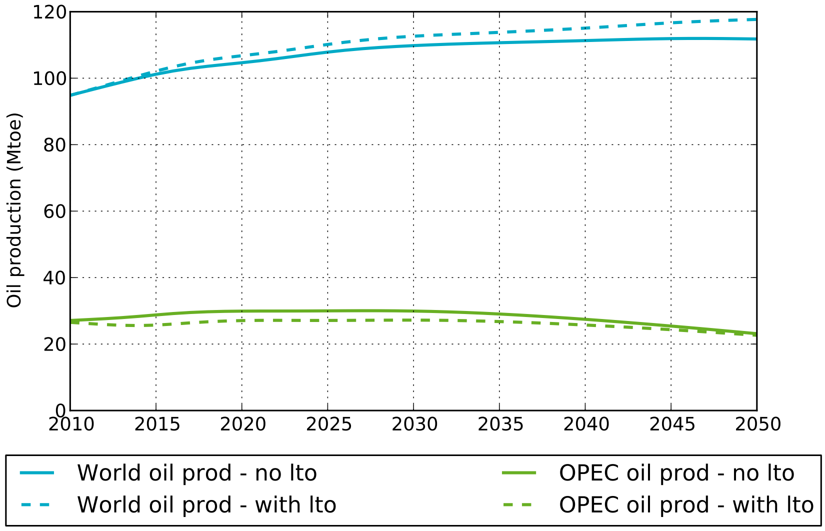


Figure 9: World and OPEC oil production profiles (Mtoe).



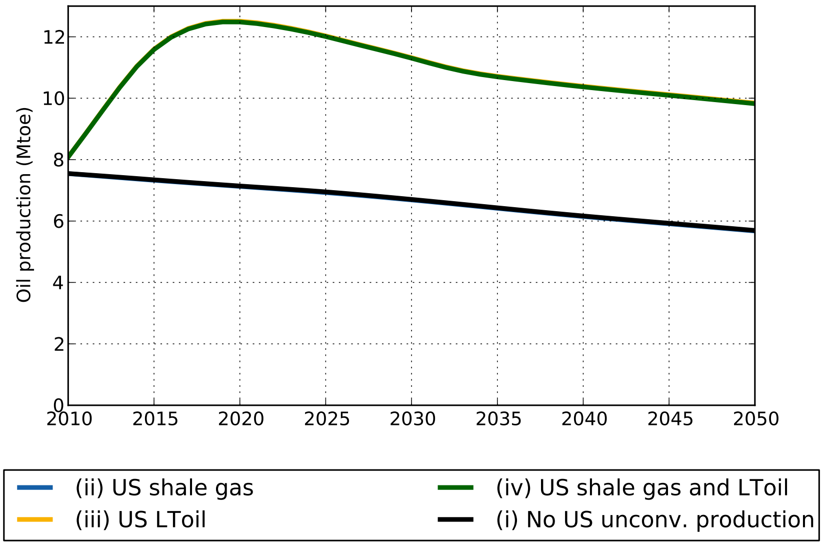


Figure 10: US oil production (Mtoe).

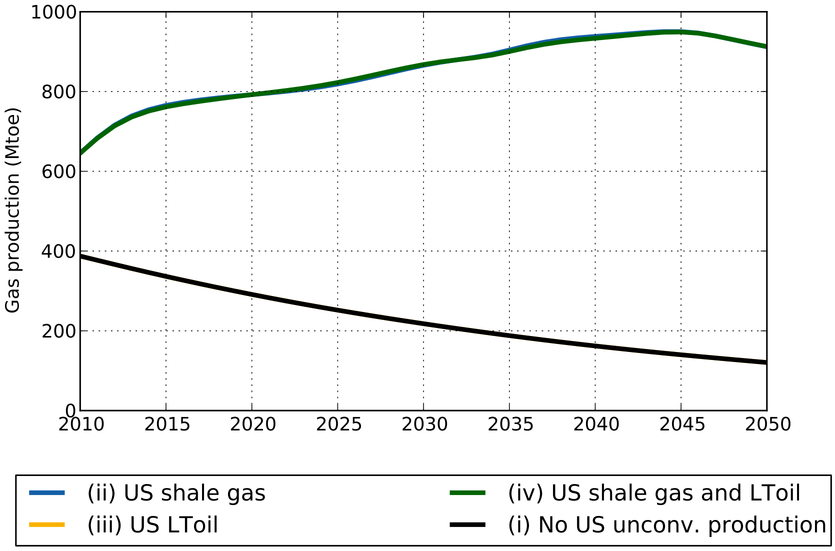


Figure 11: US gas production (Mtoe).

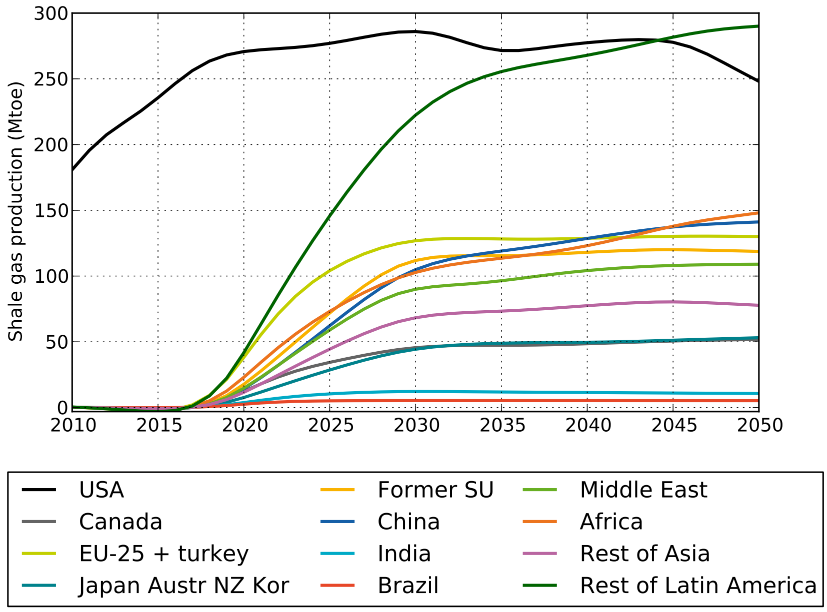


Figure 12: Shale gas production by region (Mtoe).

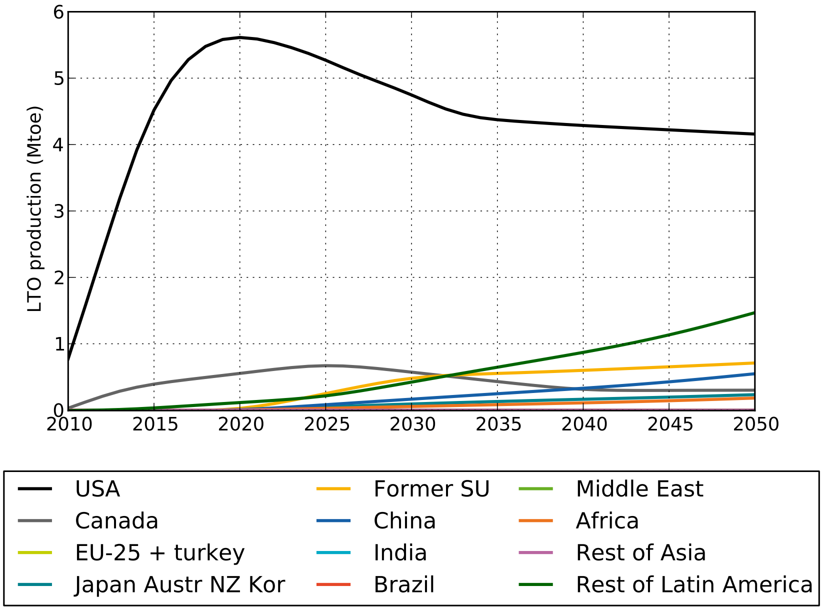


Figure 13: Light tight oil production by region (Mtoe).

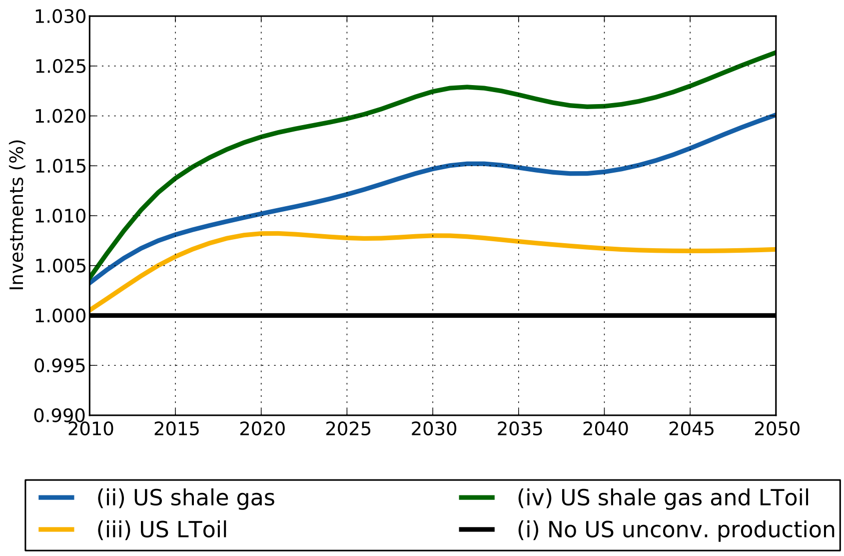


*Figure 14: Investment value of the USA, variations from scenario **(i)**.*

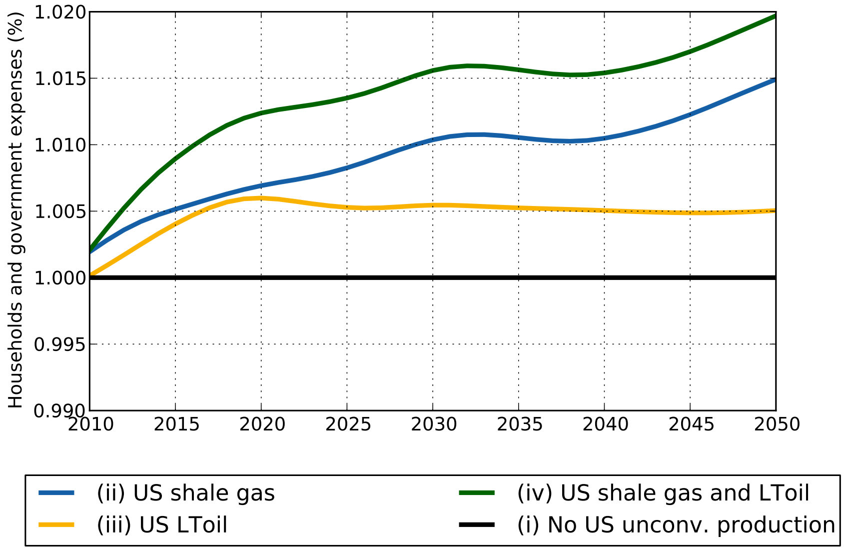


*Figure 15: Households and government demand value of the USA, variations from scenario **(i)**.*

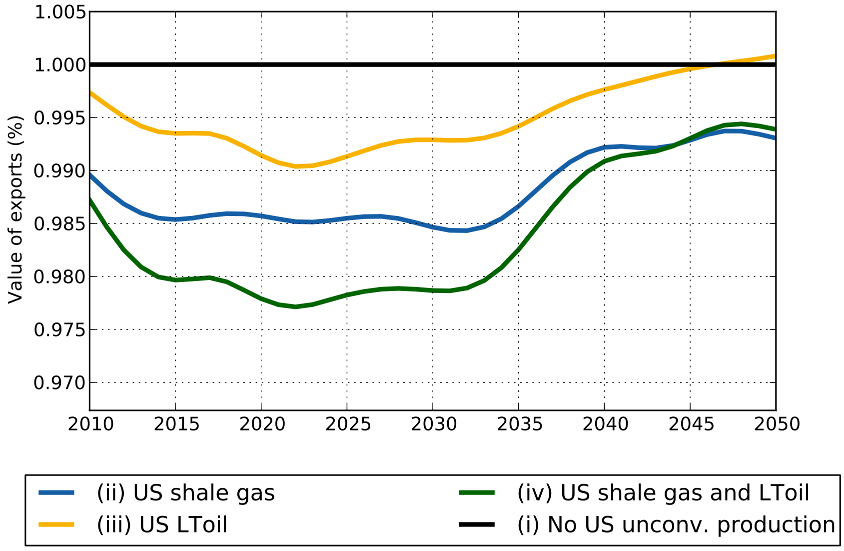


*Figure 16: Exportation value of the USA, variations from scenario **(i)**.*

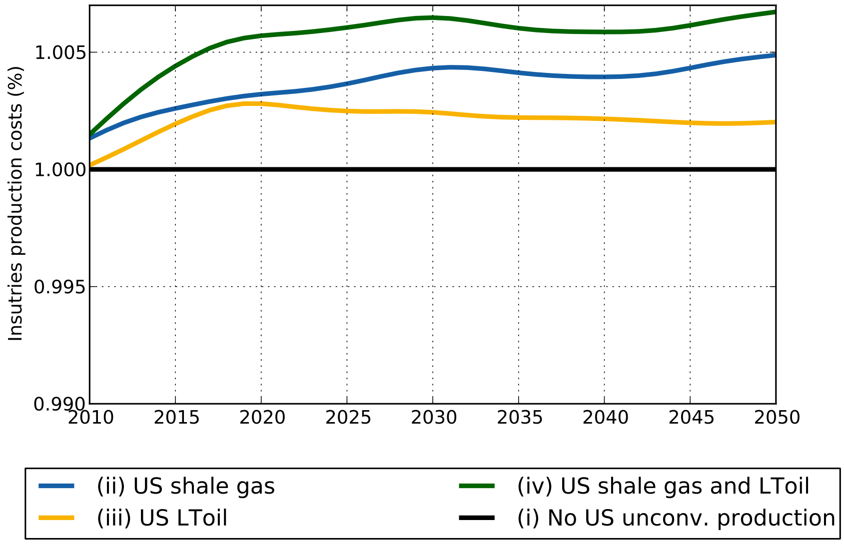


*Figure 17: Energy intensive industries' production costs relatively to world prices, variations from scenario **(i)**.*

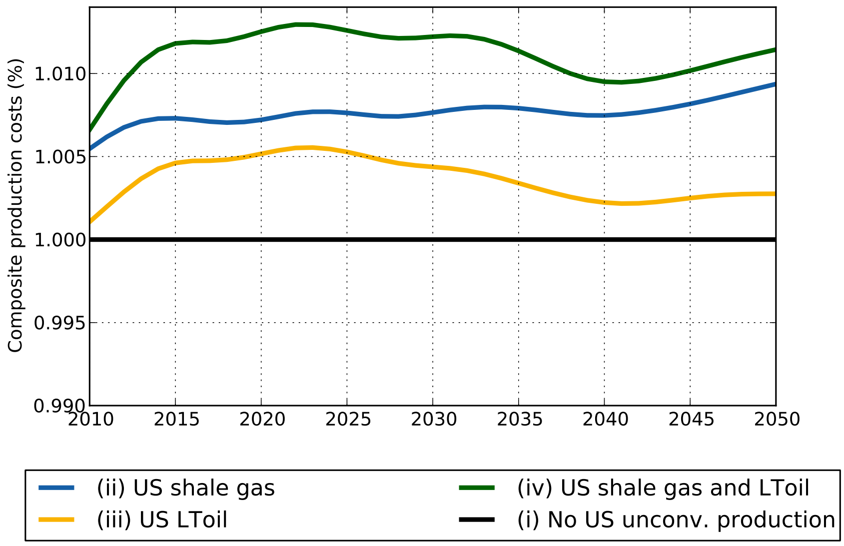


*Figure 18: Non energy intensive industries' production costs relatively to world prices, variations from scenario **(i)**.*

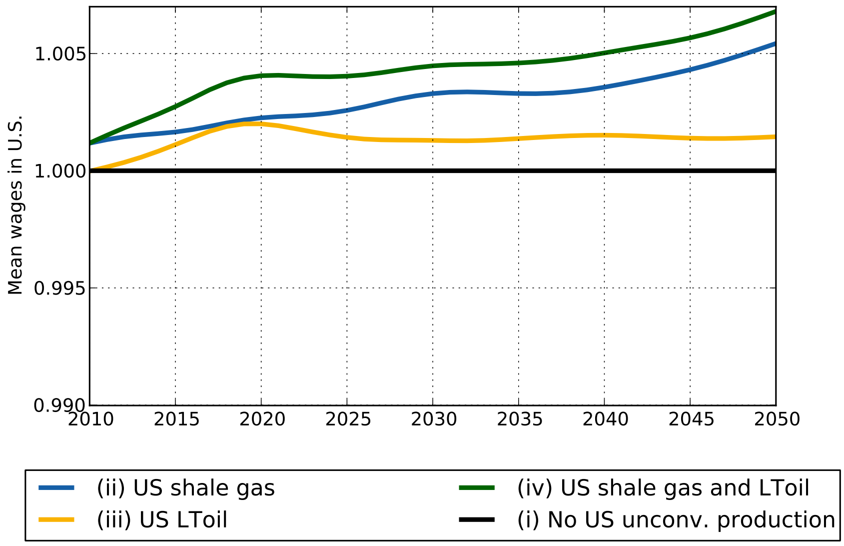


*Figure 19: Mean wages of the USA, variations from scenario **(i)**.*

	2020			2030			2040		
	Shale	Lto	Sh.Lto	Shale	Lto	Sh.Lto	Shale	Lto	Sh.Lto
Gas in electricity production	1.11	1.01	1.12	1.28	1.02	1.31	2.54	1.03	2.58
Coal in electricity production	0.94	0.99	0.93	0.9	0.98	0.88	0.7	0.99	0.7
Industrial production price	0.996	0.995	0.991	0.995	0.997	0.993	0.995	0.997	0.993
Electricity production price	0.98	0.99	0.97	0.97	0.99	0.96	0.96	1.0	0.96
Liquid fuels consumer price	0.99	0.93	0.93	0.99	0.96	0.95	1.0	0.95	0.94
Total fuel demand	0.997	1.008	1.004	0.995	1.017	1.012	0.995	1.018	1.012
Fuel use in cars	1.001	1.007	1.007	1.001	1.01	1.011	1.001	1.01	1.011
Mean wage	1.002	1.002	1.004	1.003	1.001	1.005	1.004	1.002	1.005

*Table 9: Relative change compare to the reference case scenarions (in%) for the three scenarios **(ii)** Shale gas production the in US **(iii)**: light tight oil production in the US **(iv)** both resources : gas and coal use in electricity production ; electricity and indutrial production prices ; consumer price of liquid fuels ; total demand and personnal car use of liquid fuels; mean wages.*

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