

Fossil Fuel Price Shocks and CO₂ Emissions: The Case of Spain

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ABSTRACT

This paper focuses on the impact of oil, natural gas and coal price shocks on the Spanish business cycle from 1969 to 2013. It uses Bayesian procedures to estimate a Dynamic Stochastic General Equilibrium (DSGE) model for a small open economy. The paper shows that natural gas and coal shocks are relevant sources of macroeconomic disruption in addition to oil price shocks. The three fossil fuel prices have an impact on the economic activity and explain the evolution of the energy mix. However, we find that oil price shocks have a significantly larger impact on economic volatility. Finally, we assess the impact of hydrocarbon price shocks on carbon emissions given that different price shocks result in a different fossil fuel mix and, thus, in different CO₂ emissions.

Keywords: Energy prices, Fossil fuels, DSGE models, Bayesian estimation, Small open economy, CO₂ emissions

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1. INTRODUCTION

The objective of this paper is to assess the impact of oil, natural gas and coal price shocks¹ on the Spanish business cycle and CO₂ emissions from 1969 to 2013. The composition of the fossil fuel energy mix plays a role in the transmission of energy shocks, but this tends to be ignored. For example, the decline of oil share in the fossil fuel energy mix could be a relevant reason for the ameliorated impact of the last oil shock on the global economy and also on the Spanish economy. According to BP (2015), oil represented 78 percent of the Spanish fossil fuel energy mix in the

1. A fossil fuel price shock is a significant unexpected change in the price of oil, natural gas or coal. In this study a price shock corresponds to a supply shock.

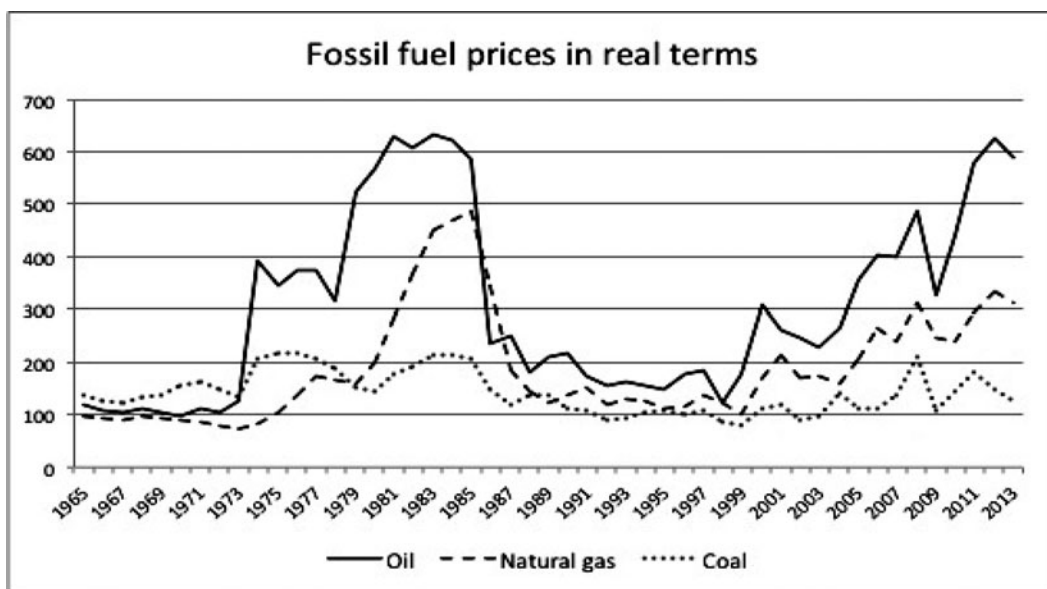
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Figure 1

70's, but only 62 percent in 2010–2013.² Given the relevant share of natural gas and coal in the fossil fuel energy mix, the volatility of the international prices of both commodities could potentially generate economic disruptions. Oil shocks and their impact on business cycles are well-studied, but to the best of our knowledge the potential economic impact of natural gas and coal price shocks has not been studied under a general equilibrium theoretical framework. Additionally, the evolution of fossil fuel prices could have an impact on carbon emissions, making achieving environmental targets easier or more difficult. Figure 1 shows the evolution of fossil fuel prices for the timeframe of this study. Oil and natural gas prices show similar volatility, while oil price volatility is twice that of coal.

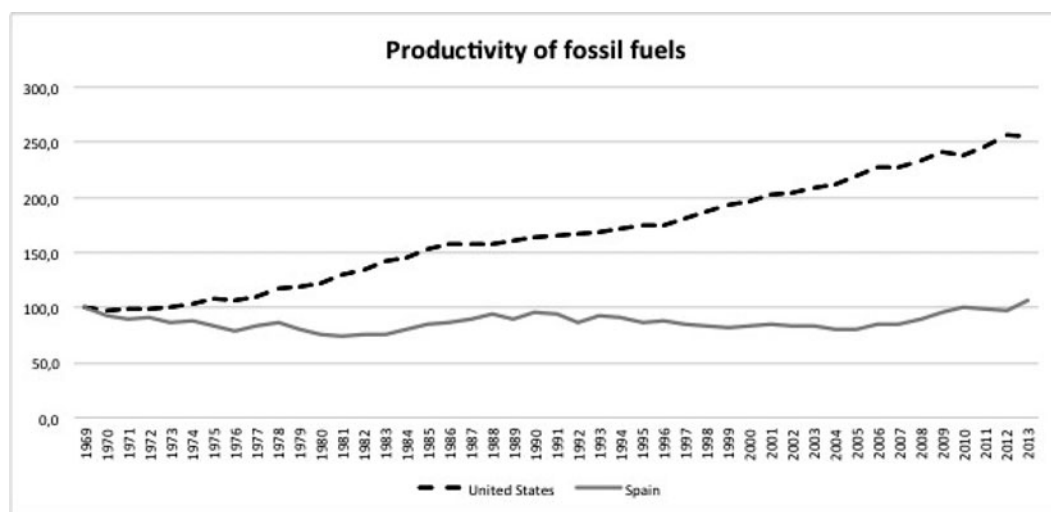
On the other hand, the evolution of energy productivity is an interesting feature of the Spanish economy. A systematic increase in energy productivity for fossil fuels is a common characteristic of many economies (see Atallah and Blazquez (2015), for example). Surprisingly, energy productivity in Spain has stagnated over the last 40 years. The efficiency of Spain's energy use is not improving, making the economy less resilient to fossil fuel price shocks. Additionally, the lack of improvement in energy productivity tends to increase carbon emissions. In most cases, CO₂ emissions are positively linked to economic activity and negatively linked to energy productivity. A higher level of economic activity requires higher energy consumption and thus results in higher

2. Spanish Fossil Fuel Mix

	Oil	Natural gas	Coal
1970–1979	78%	2%	20%
1980–1989	70%	4%	26%
1990–1999	68%	10%	22%
2000–2009	63%	21%	16%
2010–2013	62%	27%	11%

Source: Authors' calculations based on BP (2015)

Figure 2



CO₂ emissions. In contrast, higher energy productivity leads to lower demand for energy and a lower level of emissions. Figure 2 shows the evolution of energy productivity in Spain and in the USA to illustrate this point. Given this relevant and unusual feature of the Spanish economy, this paper also addresses the cyclical properties of energy productivity.

In order to analyze the role of fossil fuel price shocks on aggregate fluctuations, we use Bayesian procedures to estimate a Dynamic Stochastic General Equilibrium (DSGE) model. We consider Spain to conduct this study for two reasons. The first is that Spain has negligible production of indigenous fossil fuels. Spain imports 99 percent of its total consumption of fossil fuels. The second reason is that Spanish demand for fossil fuels is ‘sufficiently small’ to assume that any change in this demand has no relevant impact on international prices. These two reasons support our decision to consider the international prices of fossil fuels independent from Spanish aggregate demand.

The main contributions of this study are the following: i) the approach of the paper is innovative because previous studies tend to conflate energy shocks with oil shocks and ignore the other fossil fuels. Although DSGE models are not new, the modelling of the fossil fuel energy mix is new in the literature on energy shocks. ii) The estimation results reflects that oil, natural gas and coal are ‘complements’ rather than ‘substitutes’ in the productive process. This implies that the three fossil fuels move in “parallel” when prices change. iii) We show that aggregate technological shocks have no significant impact on fossil fuel energy productivity. The reason for this behavior is that technological shocks stimulate the demand for energy, offsetting potential energy productivity gains. iv) This holistic approach to the fossil fuel mix allows us to explore the impact of hydrocarbon price shocks on carbon emissions along with the business cycle.

Finally, the relationship among fossil fuel prices and carbon emissions is not only an academic issue. There are implications for policymakers. Climate and greenhouse objectives are normally defined with a specific target in a particular year (for example a 40 percent reduction in greenhouse emissions in year 2030 compared with 1990 levels). As we will show in the paper, the evolution of fossil fuel prices has a critical impact on carbon emissions along the business cycle, which could favor or jeopardize climate targets.

The rest of the paper is organized as follows. In section 2 we review the relevant literature in the area. Section 3 describes the theoretical model. Section 4 discusses the estimation of the model. Section 5 reports the results of the model. Finally, Section 6 concludes.

2. LITERATURE REVIEW

The relationship between oil prices and economic activity has been an important topic in macroeconomic research since the oil crises of the 1970s. For example, Pindyck (1979) analyzes the impact of energy supply and demand on economic activity. Hamilton (1983, 2011) points out that most of the post Second World War recessions were preceded by a dramatic rise in oil prices. Gisser and Goodwin (1986) discuss statistical evidence on the impact of oil shocks on U.S. recessions. Mork (1989, 1994) offers evidence of an asymmetric relationship between oil prices and aggregate economic activity. Olson (1988) uses quantitative estimations to analyze the relationship among oil shocks, the fall of U.S. productivity and economic activity. Darby (1982) and Burbidge and Harrison (1984) find similar results for other industrialized countries. All these papers suggest that oil price shocks have a significant impact on economic growth and the business cycle.

Oil price shocks are still an important topic of economic research but, in general terms, more recent results are less conclusive. Using cointegration and VAR methodologies, Hooker (1996) finds that oil shocks barely contribute to aggregate fluctuations in the economy. Ferderer (1996) and Lee et al. (1995) argue that only unexpected sharp price fluctuations have a relevant impact on the economy. Kilian (2009) uses a SVAR model to analyze the effects of oil price shocks on economic activity, differentiating between supply and demand shocks. Hamilton (2009) carries out a set of diverse econometric approaches to explore similarities and differences between the 2007–08 run-up in oil prices and other shocks. Cologni and Manera (2008) analyze the impact of oil prices on inflation and interest rates for the G7 countries. Lardic and Mignon (2006, 2008) conclude that the oil price was an important source of economic fluctuations in the past, but the potential macroeconomic effects were less clear in the 2000s. Finally, Rafiq et al. (2009), Tang et al. (2010), Malik (2010), Pierru and Matar (2014) and Bilgin et al. (2015), among others, explore the impact of oil shocks on different developing Asian economies.

Some studies analyze the impact of oil price on U.S. activity taking into account business cycle theory. Kim and Loungani (1992) and Finn (1995), using real business cycle models for closed economies, find that oil price shocks have a very limited impact on the U.S. economy. Blanchard and Gali (2009) analyze the effects of oil price shocks using a new-Keynesian theoretical model. Using the same methodology, De Miguel et al. (2003, 2006) calibrate a real business cycle model for different European economies and analyze how oil price shocks contribute to GDP fluctuations.

Finally, the most recent research on oil price shocks combines a dynamic stochastic general equilibrium model with an estimation of the model parameters using Bayesian techniques. This approach is often called the *New Macroeconometrics*. Using this methodology, Medina and Soto (2005) analyze the role of Chilean monetary policy when there is an oil shock and Sanchez (2008) explores the transmission of oil shocks to macroeconomic variables.

Our research focuses on an unexplored area in the field of real business cycles: the impact of natural gas³ and coal price shocks on economic activity, energy productivity and carbon emissions. Hence, we expand the standard dynamic stochastic general equilibrium model to take into

3. See Arora and Lieskovsky (2014).

consideration the three fossil fuels: oil, natural gas and coal. Finally, we also choose Bayesian methods to estimate the parameters of the model rather than carrying out a standard model calibration.

3. THE MODEL

We develop a version of a neoclassical growth model. We represent the Spanish economy using a dynamic stochastic general equilibrium model, assuming rational expectations and the characteristics of a small open economy. In this model households, firms and the external sector interact by trading a final good, government bonds and three energy inputs. Finally, there are four possible sources of macroeconomic fluctuations: a productivity shock and three fossil fuel price shocks (crude oil, coal and natural gas). Time is discrete and infinite. The online Appendix 1 includes a detailed resolution of the model.

3.1 The Household

The economy is made up of a representative household, which obtains utility from the consumption of final goods and leisure. The representative household maximizes its expected utility defined over the stochastic sequences of consumption and labor subject to a budget constraint,⁴

The household total income consists of three components: labor income, the return on the real capital stock and the real return on holdings of debt. On the other hand, the current income and financial wealth can be used for consumption, investment in physical capital and changes in his/her portfolio.

3.2 The Firm

There are only three primary sources of energy in this economy: crude oil, natural gas and coal⁵ that are used as inputs in the production function for final goods and services. The firm also uses labor and capital as inputs. The technology of the production function for final goods (F) is a Cobb-Douglas technology, while the production functions regarding fossil fuels, G and H , are Constant Elasticity of Substitution technologies.⁶

4. Please note that energy services are embedded in the utility function of the household through private consumption. The model considers the different forms of energy as intermediate inputs used to produce final energy, which in turn is used as input to produce the final product (Y). In this sense, part of this production goes to private consumption; so these energy services are already implicitly incorporated in the variable C_t that appears in the utility function.

5. We are aware that nuclear and renewable energy play a relevant role in the Spanish energy system. However, our model does not take these energy sources into consideration. We focus on the impact of unexpected fossil fuel price changes on the business cycle, rather than on energy policies. Renewable and nuclear energy consumption responds to political strategies that have to do with environmental concerns, energy security, industrial development, etc. In any case, these energies represent only around 18 percent of total energy consumption.

6. Using a Cobb-Douglas function which combines labor, capital and energy in order to model the production of the final good is standard in macroeconomic literature because it is consistent with stable shares of factors payments on national income, as shown by the data (see Golosov et al, 2014). However, we propose a more general structure, the CES function, for the energy part of the model. The reason is that the estimated values for the parameters of the CES function allow to reflect different degrees of complementarity or substitution between these intermediate inputs, and this is a key point of the paper.

Table 1: Matrix of Correlations for Fossil Fuel Prices

	Oil	Natural gas	Coal
Oil	1	0.80	0.58
Natural Gas		1	0.43
Coal			1

$$Y_t = Z_t F(K_t, N_t, G(E_{o,t}, H(E_{g,t}, E_{c,t})))$$

where Y_t is the final good, N_t represents labor, K_t is the stock of capital, $E_{o,t}$ is oil, $E_{g,t}$ is natural gas and $E_{c,t}$ is coal. Finally, Z_t is the total factor productivity shock. The G and H functions model the combination of the three fossil fuels as intermediate inputs necessary for the production of the final good (see online appendix 1 for more details, <https://www.iaee.org/energyjournal/issue/3000>).

The firm which produces the final goods and services is perfectly competitive and maximizes profits subject to the technological constraint, according to which energy intermediate inputs are necessary to produce the final good, that is, the producer of the final good is constrained by energy costs and energy production process.

3.3 Potential Shocks to the Economic Eystem

In this economic environment, there are four potential sources of uncertainty: 1) productivity shocks, 2) oil price shocks, 3) natural gas price shocks and 4) coal price shocks. Productivity shocks are assumed to follow a standard first-order autoregressive process.

With respect to fossil fuels, academic literature generally focuses on oil prices as the main source of energy shocks, ignoring natural gas and coal prices. However, natural gas and coal prices do not necessarily move in parallel with oil. Because one major purpose of the paper is to unveil potentially distinct macroeconomic effects from the different fossil fuels, we have opted for estimating the dynamic and contemporaneous stochastic relationships between them by fitting a multivariate vector autoregressive process (VAR) to fossil fuel data and using thereafter the results as an input for the DSGE model.

In this line, Table 1 shows the simultaneous correlations among prices for the three fossil fuels for the period 1969–2013. These prices are correlated at different degrees, suggesting that oil, natural gas and coal price shocks are not independent.

In order to carry out an impulse response analysis, we use a Cholesky decomposition of the variance-covariance matrix. This implies the need to identify the structural shocks by ordering the price shocks for oil, natural gas and coal. We assume that an oil shock will also affect contemporaneously the prices of natural gas and coal; a natural gas price shock will affect contemporaneously the coal price and a coal price shock will not instantaneously affect oil and natural gas prices. This specification is based on the following evidence. First, the oil market is global, meaning that oil shocks are immediately transmitted all around the world. Natural gas and coal are regional markets. Second, natural gas markets are dominated by long-term contracts, usually linked to oil prices. For this reason, natural gas prices tend to react to changes in oil prices. Finally, a significant portion of natural gas and coal is consumed in electricity generation. In most electricity markets, natural gas prices determine the marginal cost of production, and thus the price of electricity. The demand for coal reacts to changes in those prices and, therefore, so do the prices of coal.

Figure 3 describes the temporal evolution of the hydrocarbon prices according to the estimated VAR. The results of the VAR estimation are key to understanding the results of the DSGE model.

Figure 3 shows that oil is the fossil fuel with the largest innovations or largest shocks, followed by natural gas and coal. The most relevant characteristic of this Figure is the different evolution of the hydrocarbon prices in the medium term. An oil price shock leads to a persistent increase in the prices of natural gas and coal. A natural gas price shock initially generates a similar response in coal prices, but afterward the prices of the three commodities decline. This evolution will be critical to understanding the impulse response functions of our model to price shocks. In the case of a coal price shock, the VAR shows different characteristics from the previous cases. First, the volatility is half that of the previous two cases and second, coal price evolution is always positive while natural gas and oil prices have a mild negative evolution.⁷

4. ESTIMATING THE MODEL

We solve the model through the Blanchard-Kahn (1980) procedure. First, we log linearized the optimality conditions (see online Appendix 1) and second, we solve the expectations to obtain the model's solution. Online Appendix 2 has a detailed explanation of the process.

4.1 Data

We estimate the DSGE model using four time series for the Spanish economy filtered by HP,⁸ generating stationary business cycles: (1) real consistent output,⁹ (2) oil consumption, (3) natural gas consumption, and (4) coal consumption. We believe that these series capture the main dynamic aspects of the data and they contain much of the information in which we are interested. The sample ranges from 1969 to 2013 using annual data.

BP Statistical Review of World Energy 2014 is the main source for international fossil fuel prices and national primary energy consumption. In the case of crude oil, we use Brent as the representative price for Spain for the period 1976–2013. For the previous years, 1969–1975, we use the Dubai oil price, given the lack of data for Brent. The Northwest Europe market price is the representative price for coal in the period 1987–2013. For the period 1969–1987, we use the sea-borne US Central Appalachian coal spot price as the reference for price movements in Europe, assuming that both series have a similar annual rate of growth.

Regarding the import price of natural gas, this is not available. For this cause and for the period 1984–2013, we use the average German import prices as a proxy of the price of Spanish imports. The reason behind this assumption is that natural gas markets in Europe are connected, reducing regional divergences in prices. For the period 1969–1983 given the lack of information for German import prices, we generate the gas price using prices provided by the US Energy

7. We want to highlight that we ran the model using a different characterization for the causality of fossil fuel innovations. In particular, natural gas shocks contemporaneously affect oil and coal prices and oil prices contemporaneously affect coal prices. The qualitative results found hold under this VAR specification.

8. A value of the lambda parameter equal to 400 has been chosen. A sensitivity analysis using other values for lambda has been carried out, and the results still hold.

9. The real consistent output is defined as the real GDP plus the consumption of oil, natural gas and coal in real terms.

Figure 3: Impulse Responses of Prices

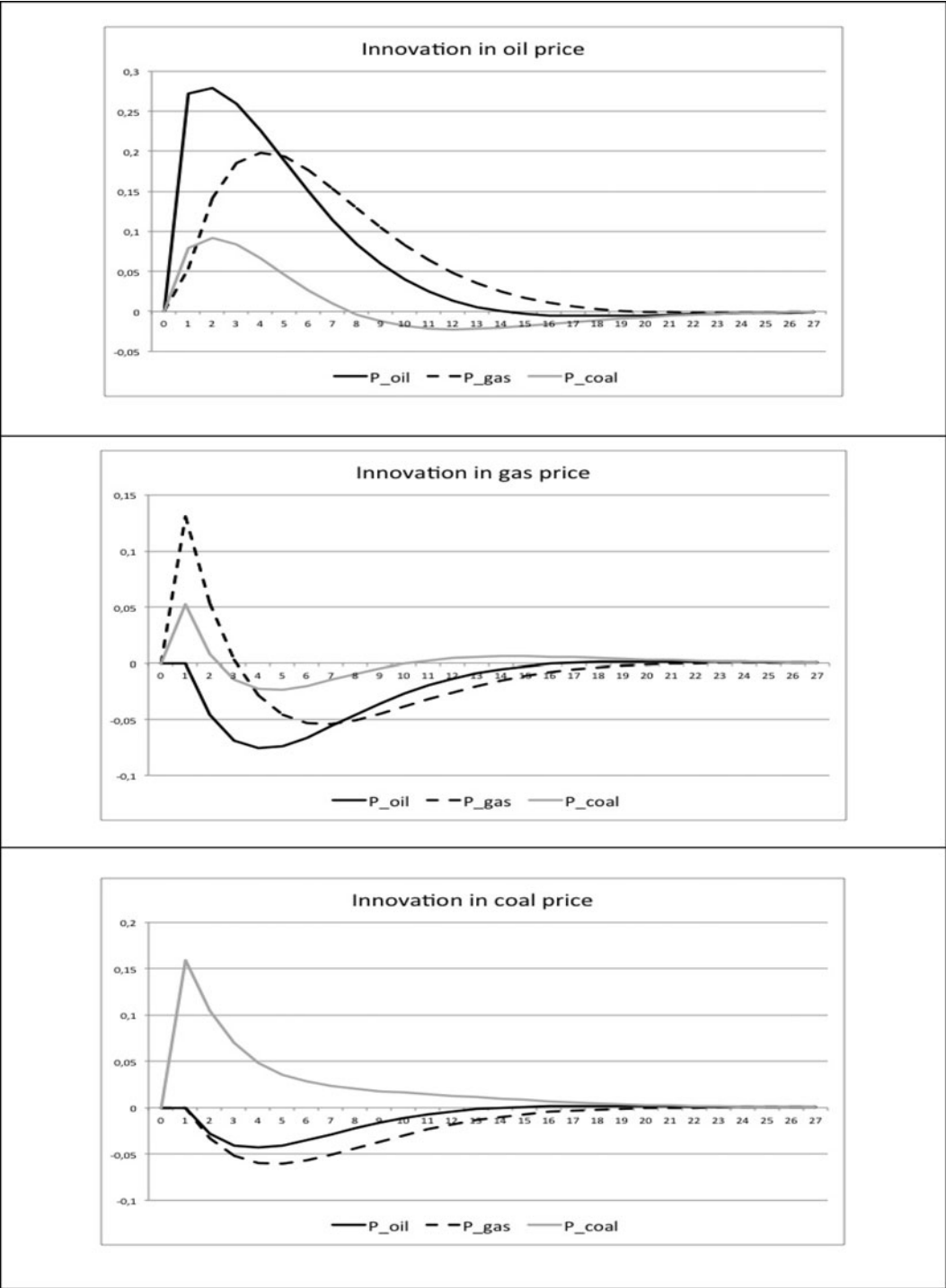
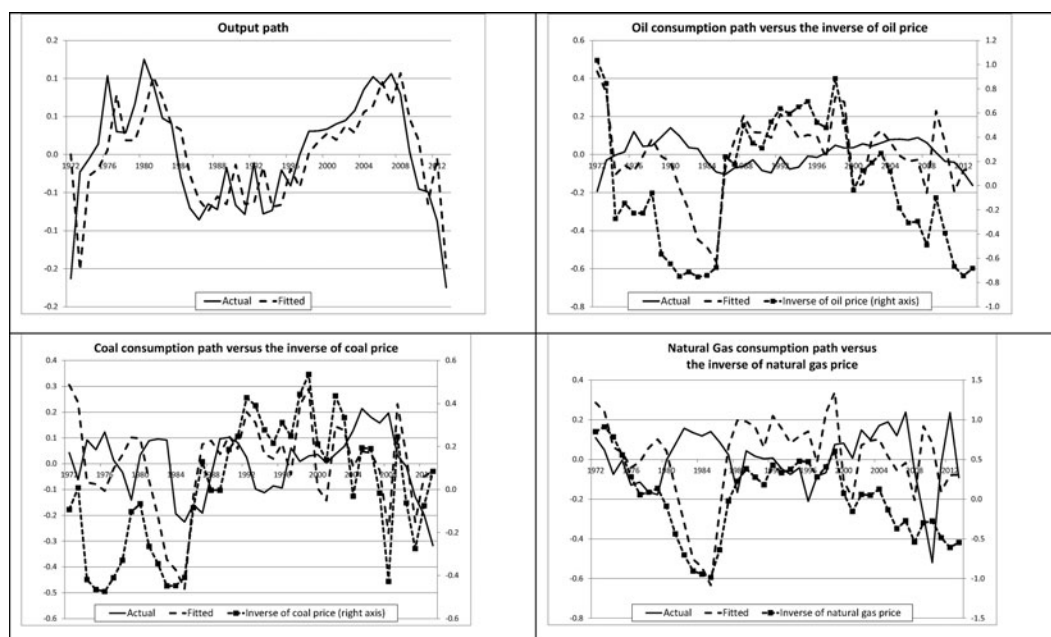


Figure 4: Model Fit. HP Filtered Series using $\lambda = 400$ 

Information Administration. All nominal prices have been converted to euros per ton of oil equivalent.

Finally, the Spanish GDP is obtained from the European Commission database.

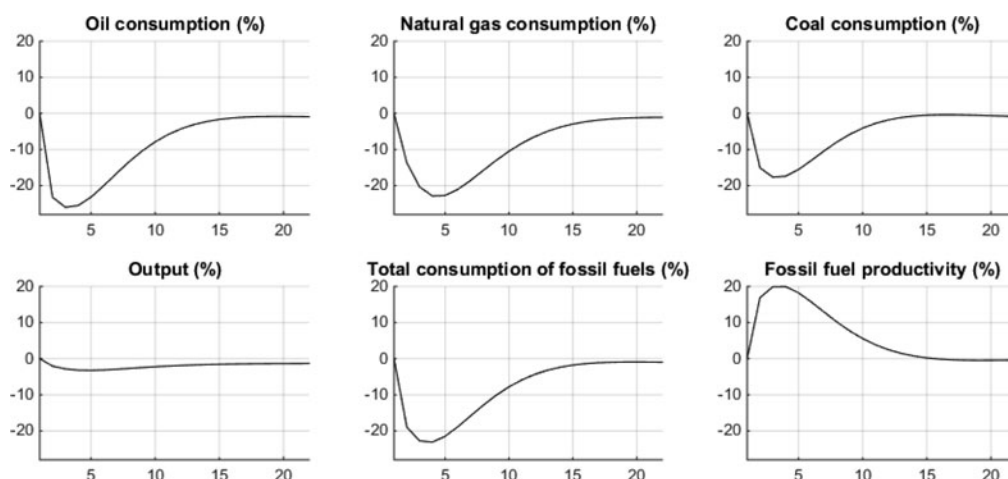
5. IMPLICATIONS OF THE MODEL

This section analyzes how price shocks for the three hydrocarbons contribute to fluctuations in the main economic variables. To this end, we first assess the overall fit of the model. Second, we simulated the model to obtain the impulse responses to the different types of shocks and the variance decompositions of the main variables. We must highlight that, to the best of our knowledge, this is the first study that focuses on natural gas and coal price shocks by estimating a DSGE model and, thus there is no previous literature on this issue.

5.1 Assessing the Fit of the Model

We need to assess the overall goodness of fit of the model before analyzing how the model helps us to understand how shocks contribute to aggregate fluctuations in the Spanish economy. A first test is to compare the time path of the series used in the estimation process with the model's predictions for the same variables. Figure 4 compares observed data and model predictions for the series included in the estimation data set: i) real consistent output, ii) oil consumption, iii) natural gas consumption, and iv) coal consumption.

We see that the model does a very good job of replicating the cyclical path of aggregate output in the economy. However, the discrepancies between the observed and modeled energy variables are relevant. Our study focuses on the impact of international hydrocarbon price shocks on the Spanish business cycle rather than on the energy mix itself. A country's energy mix combines

Figure 5: Impulse Response Function to an Oil Price Shock

the evolution of international fossil fuel prices, technological conditions, household preferences and energy policies. Our model takes no heed of energy policies, which may be why it does not reproduce the Spanish energy mix. However, the steady state of the model is similar to the world fossil fuel mix,¹⁰ suggesting that in the absence of distorting policies or taxes, the ‘theoretical’ fossil fuel mix of the Spanish economy should be quite similar to the world fossil fuel mix.

5.2 Impulse Responses

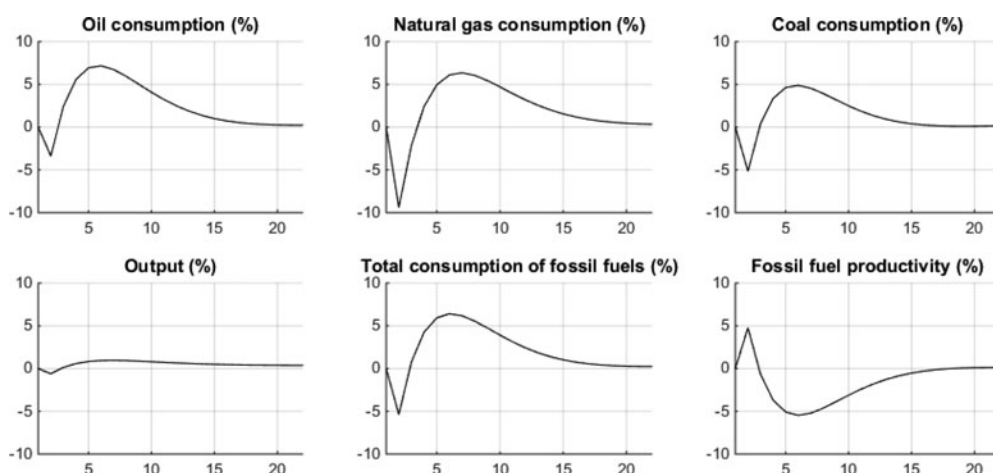
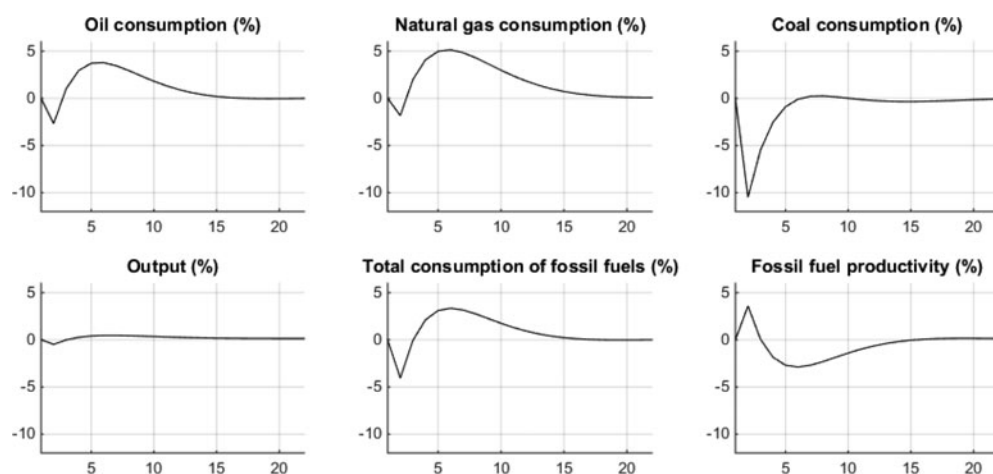
To better understand the propagation mechanisms implied by the model, this subsection analyses the effects of fossil fuel price shocks in Spain.

As expected, oil price shocks have a negative, large and persistent impact on economic activity. As the prices of energy inputs increase, there is a negative impact on economic activity. The total consumption of fossil fuel energy goes down, but the impact on energy productivity is positive because the decline in fossil fuels is greater than the decline in output. The shift toward labor and capital leads to this result, given that the relative prices of these inputs are now lower compared to the prices of fossil fuels. Figure 5 summarizes these results.

Oil shocks and natural gas and coal price shocks have different overall impacts. As expected, natural gas and coal price shocks initially have a negative impact on fossil fuel consumption and output. The initial impacts are similar to those for oil, but their magnitude is smaller. However, they subsequently evolve very differently across time than for oil. Figures 6 and 7 illustrate that, after the first period, the initial impact reverses. Output and fossil fuel consumption increase and energy productivity decreases. These patterns are more pronounced for natural gas and less intense for coal. The evolution of prices in the midterm provides the reason for this apparently odd model

10. Energy mix

	Model	World	Spain
Oil	43%	45%	69%
Natural gas	27%	24%	11%
Coal	30%	31%	20%

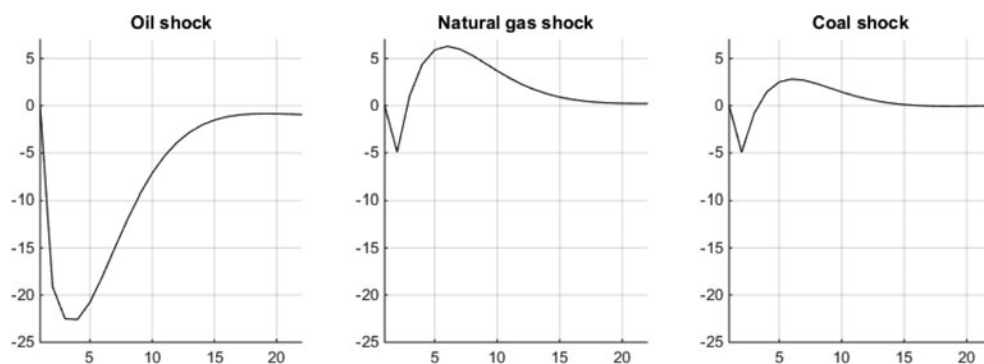
Figure 6: Impulse Response Function to a Natural Gas Price Shock**Figure 7: Impulse Response Function to a Coal Price Shock**

behavior. After the initial price shocks, natural gas and oil prices decrease, with a positive impact on economic activity and on the demand for fossil fuels. Logically, fossil fuel productivity initially improves, but the effect turns negative later on.

5.3 CO₂ Emissions

One implication of our holistic approach to the fossil fuel mix is that it allows us to analyze the impact of energy price shocks on CO₂ emissions. Using the data reported by the International Energy Agency (2011), we transform fossil fuel consumption into carbon emissions.¹¹ The results

11. The International Energy Agency (2011) provides references to convert fossil fuel use to CO₂ emissions: emissions from crude oil are 610 g/kWh, emissions from natural gas are 370 g/kWh and emissions from coal are 897 g/kWh (the average emissions from lignite, other sub-bituminous and sub-bituminous coal types).

Figure 8: Impulse Response Function of Carbon Emissions

show that, logically, emissions are driven by total consumption of fossil fuels. CO₂ emissions move in parallel with total energy consumption. Figure 8 shows the evolution of carbon emissions when there is a fossil fuel price shock.

According to our findings, shocks in the price of oil and natural gas do not significantly change the relationship between CO₂ emissions and consumed energy in calorific terms. However, when there is a coal price shock, the energy mix shifts toward natural gas and, to a lesser extent, to oil. Thus, there are fewer emissions per calorific unit of energy consumed.

5.4 Variance Decomposition

We now estimate the model of section 2 accounting for all four shocks. This approach allows us to compute each shock's contribution to aggregate fluctuations. Table 2 reports the variance decomposition of the most relevant variables for the Spanish economy at various terms. Again the estimated contribution of each shock to the relevant variables appears to be very reasonable.

Productivity shocks and oil price shocks mainly explain the forecast error variance of fossil fuel consumption. The preeminence of oil shocks over natural gas and coal shocks is explained by the way we defined innovations in the VAR for prices. In the case of natural gas consumption, a price shock has a relevant impact on variance of around 10 percent. A coal price shock seems to have a very limited impact on consumption of all fossil fuels, including coal. Logically, productivity shocks explain the variance of the total fossil fuel consumption.

Productivity shocks explain most of the error variance in the output forecast. The rest of the shocks have a marginal impact on the variance of Spanish output. Productivity shocks have a negligible impact on the variance of energy productivity because energy productivity is a ratio, with GDP as the numerator and the sum of energy consumptions as the denominator. Productivity shocks strongly affect both the numerator and denominator, so the energy productivity is explained by fossil-fuel shocks, in particular those of oil and natural gas.

Finally, the decomposition of the variance of carbon emissions is a balanced combination of productivity shocks and fossil fuel price shocks. The reason behind this behavior is that changes in economic activity and consumption of hydrocarbons as well as changes in the composition of the fossil fuel mix have an impact on emissions volatility.

6. CONCLUSIONS AND POLICY IMPLICATIONS

A significant number of studies focus on the impact of energy price shocks on macroeconomic fluctuations. However, academic research tends to conflate energy price shocks with oil

Table 2: Variance Decompositions

A. The contribution (%) of shocks to oil consumption					B. The contribution (%) of shocks to gas consumption				
Periods	Productivity	Oil price	Natural gas price	Coal price	Periods	Productivity	Oil price	Natural gas price	Coal price
1	40.58	57.41	1.23	0.78	1	57.66	28.41	13.40	0.53
2	39.33	59.41	0.85	0.41	2	53.39	39.97	6.16	0.49
3	39.41	58.54	1.52	0.53	3	50.17	44.94	3.94	0.95
4	40.52	56.49	2.27	0.72	4	48.75	46.40	3.48	1.37
5	42.34	53.95	2.85	0.87	5	48.70	46.10	3.55	1.65
10	54.20	41.52	3.37	0.91	10	56.57	37.82	3.81	1.80
Inf	83.82	14.63	1.23	0.32	Inf	84.75	13.23	1.39	0.63

C. The contribution (%) of shocks to coal consumption					D. The contribution (%) of shocks to output				
Periods	Productivity	Oil price	Natural gas price	Coal price	Periods	Productivity	Oil price	Natural gas price	Coal price
1	51.16	30.49	3.62	14.73	1	98.76	1.09	0.09	0.06
2	53.22	35.77	1.79	9.22	2	98.43	1.50	0.05	0.03
3	54.98	36.97	1.68	6.37	3	98.18	1.74	0.06	0.02
4	57.14	36.03	1.98	4.85	4	98.03	1.86	0.08	0.03
5	59.66	34.11	2.27	3.97	5	97.98	1.89	0.10	0.03
10	71.79	23.66	2.22	2.33	10	98.24	1.60	0.13	0.03
Inf	91.66	7.02	0.67	0.66	Inf	99.08	0.84	0.07	0.01

E. The contribution (%) of shocks to fossil fuel consumption					F. The contribution (%) of shocks to energy productivity				
Periods	Productivity	Oil price	Natural gas price	Coal price	Periods	Productivity	Oil price	Natural gas price	Coal price
1	48.45	45.72	3.69	2.13	1	0.00	88.83	7.11	4.05
2	46.55	50.77	1.71	0.97	2	0.00	94.95	3.24	1.81
3	45.89	51.59	1.75	0.77	3	0.00	95.30	3.25	1.45
4	46.46	50.48	2.23	0.83	4	0.00	94.24	4.18	1.58
5	47.89	48.50	2.70	0.91	5	0.00	93.02	5.19	1.79
10	58.90	37.06	3.14	0.90	10	0.00	90.14	7.61	2.25
Inf	86.16	12.45	1.09	0.30	Inf	0.00	89.92	7.81	2.27

G. The contribution (%) of shocks to carbon emissions				
Periods	Productivity	Oil price	Natural gas price	Coal price
1	47.85	46.00	3.07	3.09
2	46.54	50.53	1.47	1.46
3	46.32	51.02	1.64	1.01
4	47.21	49.69	2.17	0.92
5	48.89	47.55	2.64	0.92
10	60.37	35.79	3.02	0.82
Inf	86.89	11.82	1.03	0.27

price shocks. This approach could be misleading, since natural gas and coal have a relevant share of the fossil fuel mix. Using an innovative approach, this paper models the fossil fuel energy sector of a small open economy more accurately by accounting for natural gas and coal prices as well as oil prices. To assess the impact of fossil fuel price shocks on the Spanish economy, we create a

Dynamic Stochastic General Equilibrium model for a small open economy and estimate it using a Bayesian procedure.

This study shows that fossil fuel prices are strongly correlated and tend to move in parallel, suggesting that hydrocarbon prices respond to the same perturbations or shocks and affect economic activity simultaneously. Normally a sharp shift in oil prices is accompanied by a sharp shift in natural gas and coal prices. This is an additional justification for considering a holistic modeling of the energy sector at a macro level.

A result of the estimation of the model is that oil, natural gas and coal are complementary inputs, meaning that oil, natural gas and coal consumption tend to move in parallel. In other words, the economy demands simultaneously more (or less) oil, natural gas and coal. An increase in oil prices not only decreases the demand for oil, but the demand for gas and coal as well. To the best of our knowledge, this is the first time that these parameters have been estimated at a macroeconomic level.

We find that productivity shocks and, to lesser extent, oil price shocks explain most of the volatility of output, while the contribution of natural gas and coal price shocks is marginal. Paradoxically, productivity shocks have a negligible impact on energy productivity. Nevertheless, the three fossil fuel prices are relevant to understand the evolution of fossil fuel consumption and carbon emissions.

Policymakers tend to define carbon emission targets independently from the macroeconomic environment. For example, the European framework on climate and energy 2030 sets a 40 percent reduction in greenhouse emissions below the 1990 level as a binding target. This reduction is independent from the cyclical situation of the economy and from fossil fuel price levels. Our study shows that the volatility of carbon emissions, and thus the level of carbon emissions in a particular year, is influenced by productivity shocks and fossil fuel prices. A sharp increase in fossil fuel prices favors a significant decrease in carbon emissions and the same happens when there is a negative technological shock. Thus, the success of the European climate and energy agenda will depend on the policy implemented, but it will also depend critically on the level of fossil fuel prices. The definition of alternative carbon emission targets is out of the scope of this study, but the cyclical component of emissions is something that must be addressed to evaluate climate policies.

This study does not consider the role of energy policies that could substantially change the impact of fossil fuel prices on economic activity, the demand for primary energy and carbon emissions. This could be a potential line of future research.

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