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## The Welfare Cost of Energy Insecurity

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## Abstract

Although energy security is considered as an important objective of energy policy in many countries, there is limited information about the consequences and the economic impact of energy insecurity. Most of the literature on energy security has focused on the definition and indicators, and little attention has been placed on quantifying its economic cost. The aim of this paper is to contribute to this literature quantifying the welfare cost of energy insecurity. We focus on the economic risks and, therefore, we relate energy security to the volatility in the energy price. A standard Dynamic Stochastic General Equilibrium (DSGE) model is used to quantify the welfare cost of energy price fluctuations. We calibrate the model for the Spanish economy, and find that in the last 30 years the welfare loss of energy insecurity has been around 0.8% of average consumption as a percentage of output.

**JEL classification:** Q43, E32

**Keywords:** Energy security, Welfare cost, Price volatility

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# 1 Introduction

The 1973-1974 oil crisis revealed the vulnerability of the industrial countries to oil price shocks. The oil embargo by a number of Arab producers led to a sharp rise in oil prices, which caused a decline of economic activity. Since then, energy security is considered as an important objective of energy policy in many countries around the world. An example is the creation in 1974 of the International Energy Agency (IEA), whose primary mission is to help member countries to coordinate a collective response to major disruptions in oil supply. The increasing uncertainty in energy markets in recent years has made energy security be a major issue in the energy domain again. For instance, the European Union has included energy security as one of the three pillars of its energy policy, together with efficiency and sustainability (European Commission (EC) 2008; European Commission (EC) 2006).

Despite the importance of energy security, there is limited information about the consequences and the economic impact of energy insecurity. The literature on energy security has mainly focused on the definition and indicators of energy security.

Probably the most accepted definition is that of the IEA, which defines energy security as “the uninterrupted physical availability at a price which is affordable”. European Commission (2000) extends the IEA definition, with the inclusion of environmental and sustainability issues. The Asia Pacific Energy Research Centre (APEREC, 2007) defines energy security as “the ability of an economy to guarantee the availability of the supply of energy resources in a sustainable and timely manner with the energy price being at a level that will not adversely affect the economic performance of the economy”. According to that view, energy security is affected by four factors: availability, accessibility, affordability and acceptability. From an economic perspective, Bohi and Toman (1996) define energy insecurity as the loss of welfare resulting from a change in the price or physical availability

of energy.

Another strand of the literature has focused on the measurement of energy security. The literature on indicators of energy security is quite extensive. In a survey that oversees this field, Kruyt et al. (2009) state that there is no ideal indicator and, therefore, it is needed the application of several indicators for a broader assessment and understanding of energy security. Scheepers et al. (2007) propose two quantitative indicators: the Supply/Demand Index based on objective information contained in energy balances and the Crisis Capability Index, which measures the ability of countries to manage short-term supply interruptions. The IEA has developed a Model of Short-Term Energy Security (MOSES) to evaluate short-term security of energy supply in IEA countries (IEA, 2011). The model is based on a set of quantitative indicators that measures both the risk of disruptions in energy supply and the ability of the energy system to deal with those eventual disruptions.

So far the literature has provided useful information on the definition and indicators of energy security. However, it is unclear whether energy security is important from an economic point of view. Few studies have attempted to estimate the cost of energy insecurity. Hence, in this paper we try to go a step beyond the definition and indicators of energy security. The aim of this paper to contribute to this literature quantifying the welfare cost of energy insecurity.

The definition and indicators of energy security make clear that the estimation of the welfare cost is not straightforward. In order to quantify the welfare cost, it is necessary to consider different dimensions of energy security. The European Commission's Green Paper on the security of energy supply (EC, 2000) identifies several sources of energy risks: physical risks (permanent and temporary energy disruptions), economic risks (volatility in energy prices), political risks, regulatory risks, social risks and environmental

risks.

However, from a financial perspective, we can consider that all risks are reflected in the price. In a perfect market, futures prices capture the probability of future events, so that prices internalize all possible risks. As argued by Killian (2009), oil supply disruptions are reflected in the price of oil. Exogenous political events, such as the Iranian Revolution or the Persian Gulf War, lead to physical supply disruptions and higher precautionary demand, which ultimately translate into higher prices. Hence, in this paper we focus on the price dimension of energy risks. We relate energy insecurity to the uncertainty in energy prices, and therefore, estimate the welfare cost caused by energy price fluctuations.

To calculate the welfare cost of energy price volatility, we use a standard representative-agent Dynamic Stochastic General Equilibrium (DSGE) model. Energy enters the model as both an input in the production function and a good in consumers' utility function. Energy price fluctuations lead to increase the volatility of output, energy and non-energy consumption, leisure and investment. Thus, the welfare of risk adverse households decreases with increasing fluctuations in energy prices. There are three key parameters in the model: the elasticity of substitution between energy and capital in the production function, the elasticity of substitution between non-energy and energy consumption in households' utility function and households risk aversion. The elasticity of substitution determines how easy it is to substitute energy for capital or non-energy consumption. When households and firms cannot substitute easily energy for other goods (i.e., a low elasticity of substitution), oil price fluctuations have a higher impact on the economy. On the other hand, households risk aversion measures the attitude toward uncertainty, and therefore, oil price volatility causes a higher welfare loss when households are more risk adverse.

We calibrate the model for Spanish economy to analyze how past en-

ergy price fluctuations have affected the economy. We use oil price data to estimate the energy price process. This can be a good proxy, since energy price volatility is mainly driven by oil volatility. In Spain, oil and gas represent around 75% of total primary energy consumption. Furthermore, in the European market, natural gas contracts are linked to the price of oil and, therefore, there is a strong link between the oil and natural gas prices (Hedenus et al. 2010). Hence, we consider that the welfare cost of energy price fluctuations can be mainly explained by oil price fluctuations.

To obtain a measure of the welfare cost of energy insecurity, we compare two scenarios. In the first scenario, we analyze an economy without fluctuations, that is, an economy where energy prices are constant. In the second scenario, we consider an economy where energy prices fluctuate and the average energy price is equal to the constant price of the economy without fluctuations. We compute the welfare of households in both scenarios, and propose as a measure of the cost of energy insecurity, the welfare difference between the two economies. We find that, in Spain, past energy price fluctuations have caused a welfare loss of around 0.8% of average consumption as a percentage of output. Energy price fluctuations lead to increase the volatility of energy consumption, which causes most of the welfare loss in our model. When we perform a sensitivity analysis for the key parameters of the model, the results show the importance of the elasticity of substitution of energy both in the production function and in the utility function. As expected, the welfare loss is higher when firms find harder to substitute energy with capital. Likewise, energy price fluctuations have a higher effect on the utility when the elasticity of substitution between energy and non-energy consumption is lower.

This paper is related with two literatures. First, our work is linked to the literature on oil price shocks. In an influential paper, Hamilton (1983) pointed out that seven of the eight postwar recessions in the United States

had been preceded by a rise in oil prices. He argued that the correlation between oil prices and output cannot just be a coincidence, and therefore claims that changes in oil prices have an effect on economic activity. These findings have been corroborated by many authors (Hamilton 1983, Burbidge and Harrison 1984, Gisser and Goodwin 1986, Raymond and Rich 1997, and Hamilton 2003)<sup>1</sup>. However, it is not obvious how the price of oil affects economic activity. The standard approach to modeling energy price shocks has been to consider imported oil as an input in the production function. Thus, Kim and Loungani (1992), Rotemberg and Woodford (1996) and Finn (2000) have studied the effects of energy price shocks in RBC models. However, there are problems in explaining economic declines based on this intermediate input cost because the share of oil in GDP is relatively small, less than 5% in a developed economy such as the US. Consequently, there is no reason to expect large effects on the economy due to higher production costs (Kilian, 2007). Bernanke (1983) stated that an increase in energy prices would primarily slow economic growth through its effects on consumers' expenditure. Changing prices may create uncertainty about the future and, therefore, consumers would respond by increasing their precautionary savings and postponing purchases of energy-intensive durable goods such as automobiles. Indeed, Hamilton (2005) stressed that higher uncertainty about future energy prices is the main mechanism through which energy shocks affect the economy.

Second, our paper is related with the literature on the welfare cost of business cycles. Lucas (1987) showed that the welfare cost of consumption volatility is small. He finds that the welfare gain of a smooth consumption path is 0.05% of average consumption. However, two strands of the literature have found that this value can be higher. First, Imrohoroglu (1988),

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<sup>1</sup>Hamilton (2005) presents a complete survey of the relation between oil prices and the macroeconomy.

Atkenson and Phelan (1994) and Krussell and Smith (1999) show that in the absence of a representative agent and complete insurance markets the welfare cost of business cycle is higher. Second, a higher cost is also found when recursive preferences<sup>2</sup> such as those in Epstein and Zin (1989) are used (Obstfeld 1994). In our model, two mechanisms lead to higher welfare costs. First, consumption volatility is not only caused by production fluctuations but also by the presence of energy goods, which leads to a higher volatility when energy price moves. Second, in contrast to Lucas (1987), we use a DSGE model and, therefore, we capture precautionary behavior. The results show that the average value of households' consumption is not the same with or without price fluctuations. In presence of price fluctuations, consumers' risk aversion leads to reduce non-energy and energy consumption (precautionary savings), which implies a lower consumption level and, consequently, a welfare loss (Fernandez-Villaverde et al 2011).

The rest of the paper is organized as follows. Section 2 introduces the model. In Section 3, we calibrate the model and describe the solution method used. Section 4 presents a measure of the welfare cost of energy insecurity and the results. In section 5 we conclude.

## 2 The Model

The model described in this section is a dynamic stochastic general equilibrium model. The economy consists of a representative household and a firm. Energy enters the model as a consumption good for households and as a production input for firms. Energy is imported from abroad at an exogenous world price ( $p$ ). Each period energy imports are paid with domestic output and, thus, current account clears. The basic structure of the model is similar to De Miguel and Manzano (2011).

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<sup>2</sup>Recursive preferences allow to separate risk aversion and intertemporal elasticity of substitution.

The representative firm uses labor ( $n$ ), capital ( $k$ ) and energy ( $ef$ ) to produce the final good. Technology is given by the following CES function

$$F(n_t, k_t, ef_t) = n_t^\theta \left( (1-a)k_t^{-\nu} + aef_t^{-\nu} \right)^{-\frac{1-\theta}{\nu}}, \quad (1)$$

where  $\theta$  is the labor share and  $1/(1+\nu)$  is the elasticity of substitution between capital and energy. The firm, which operates under perfect competition, maximizes profits

$$\max_{n_t, k_t, ef_t} F(n_t, k_t, ef_t) - w_t n_t - r_t k_t - p_t ef_t, \quad (2)$$

where  $w$  is the wage,  $r$  is the interest rate and  $p$  the relative energy price<sup>3</sup>. From firm's maximization problem, we obtain the following equilibrium conditions

$$w_t = \frac{\partial F(n_t, k_t, ef_t)}{\partial n_t}, \quad (3)$$

$$r_t = \frac{\partial F(n_t, k_t, ef_t)}{\partial k_t}, \quad (4)$$

$$p_t = \frac{\partial F(n_t, k_t, ef_t)}{\partial ef_t}. \quad (5)$$

Equations 3, 4 and 5 state that the marginal productivity of labor, capital and energy are equal to the wage, the interest rate and the relative energy price, respectively.

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<sup>3</sup>The price of the final good is normalized to one, thus,  $p$  can be considered as the relative energy price

The representative household is infinitely-lived and has preferences over non-energy and energy consumption, and leisure that are defined in the following utility function

$$U(A_t, n_t) = \frac{\left[ A_t^{1-\mu} (1 - n_t)^\mu \right]^\sigma}{\sigma} \quad (6)$$

with 
$$A_t(c_t, eh_t) = [(1 - \gamma) c_t^\alpha + \gamma eh_t^\alpha]^{1/\alpha}. \quad (7)$$

$A$  is the aggregate good that combines non-energy ( $c$ ) and energy consumption ( $eh$ ). The elasticity of substitution between non-energy and energy is  $1/(1-\alpha)$ . Notice that household's endowment of time is normalized to 1 so that leisure is equal to  $1-n$ . The representative household also accumulates capital according to the law of motion:

$$k_{t+1} = (1 - \delta)k_t + i_t, \quad (8)$$

where  $\delta$  is the depreciation rate and  $i$  is investment. Thus, the representative household maximizes expected intertemporal utility subject to the budget constraint:

$$\max_{c_t, eh_t, n_t} \mathbb{E} \sum_{t=0}^{\infty} \beta^t U(A_t, n_t) \quad (9)$$

$$\text{s.t.} \quad c_t + p_t eh_t + i_t = w_t n_t + r_t k_t, \quad (10)$$

where  $\beta$  is the discount factor. The first order conditions for households problem are:

$$U_{eh_t} = -U_{c_t} p_t, \quad (11)$$

$$U_{n_t} = -U_{c_t} w_t, \quad (12)$$

$$U_{c_t} = \beta U_{c_{t+1}} (1 - \delta + r_{t+1}). \quad (13)$$

Equations 11 and 12 state that the marginal utility of non-energy consumption is equal to the marginal utility of energy consumption and leisure, respectively. Equation 13 is the standard Euler equation that determines intertemporal consumption allocation.

The equilibrium of the economy is a sequence of prices  $\{\Pi_t\} = \{p_t, r_t, w_t\}$  and quantities  $\{\Theta_t\} = \{c_t, eh_t, n_t, k_t, ef_t, i_t, y_t\}$  such that:

1. Given a sequence of prices  $\{\Pi_t\}$ ,  $\{c_t, eh_t, n_t, i_t\}$  is a solution to the representative household's problem;
2. Given a sequence of prices  $\{\Pi_t\}$ ,  $\{k_t, ef_t, n_t\}$  is a solution to the representative firm;
3. Given a sequence of quantities  $\{\Theta_t\}$ ,  $\{\Pi_t\}$  clears the market.

### 3 Calibration and Solution Method

To find a numerical solution is necessary to calibrate the model. Hence, the model is calibrated following De Miguel and Manzano (2011). The parameters are chosen to reproduce the main long-run characteristics of the Spanish economy. We define one period as a quarter, and thus, set the discount factor,  $\beta$ , to 0.99, which implies a real interest rate of 1%. The depreciation rate of capital,  $\delta$ , is set to 0.025, implying an annual rate of 10%.

There are three key parameters in our model: the elasticity of substitution between energy and capital in the production function ( $1/(1 + \nu)$ ), the elasticity of substitution between non-energy and energy consumption in households utility function ( $1/(1 - \alpha)$ ) and households risk aversion ( $\sigma$ ). We

choose standard values for our benchmark simulation. Following Thompson and Taylor (1995) estimations, the elasticity of substitution between capital and energy is set to 0.76. We also set a standard value for the elasticity of substitution between non-energy and energy consumption (0.85), obtained from Goulder et al (1999). In the literature we find a wide range of estimates for the relative risk aversion, here ( $\sigma$ ) is equal to -1 which lies between the intervals of many empirical studies. In section 4.2 we perform sensitivity analysis along these three parameters and analyze how the results vary.

The parameter  $\mu$  in households utility function is 2/3 which implies that the representative household works one-third of its time. In the production function, we set a standard value for the labor share, ( $\theta = 0.64$ ). The parameters,  $\gamma$  and  $a$ , are chosen to approximate household and firm energy consumption ratios to the values observed in the data. Table 1 presents parameter values.

To estimate the price process, we use oil prices rather than energy prices. This can be a good approximation given that energy price fluctuations are mainly explained by oil price volatility. In Spain, oil and natural gas account for 75% of energy consumption and, furthermore, the price of natural gas is linked to oil price. To obtain the relative price we divide oil price by the Spanish GDP deflator. We use quarterly log prices from 1970Q1-2007Q4 to estimate

$$p_t = (1 - \rho)p_{ss} + \rho p_{t-1} + \epsilon_t \quad \epsilon_t \sim N(0, \sigma_p). \quad (14)$$

To solve the model, we use the stochastic perturbation method, i.e., linearization around the steady-state, to approximate the dynamics of our economy. We run the program Dynare Version 4.2 to obtain the policy functions (see Adjemian et al (2011) for the methodological details). Two different approaches are used to linearize the model: a first-order and a second-order Taylor expansion. As argued by Schmitt-Grohe and Uribe

Table 1: Parameter and Steady-State Variable Values

<b>Preferences</b>		
Subjective discount factor	$\beta$	0.99
Energy consumption share	$\gamma$	0.036
Elasticity of substitution between energy and non-energy consumption	$1/(1 - \alpha)$	0.85
Preference for leisure	$\mu$	2/3
Risk aversion	$\sigma$	-1
<b>Technology</b>		
Labor share	$\theta$	0.64
Rate of depreciation	$\delta$	0.025
Elasticity of substitution between energy and capital	$1/(1 + \nu)$	0.76
<b>Prices</b>		
Persistence	$\rho$	0.95
Standard deviation	$\sigma_p$	0.18

(2004) second-order approximation techniques are best suited to handle welfare comparisons. The problem is that using a first-order approximation some second-order terms of the equilibrium welfare function are ignored while others are not. For instance, a limitation of a first-order approximation is that the decision rules of the representative agent follow the certainty equivalence principle. This limitation implies that the unconditional means of endogenous variables coincides with their non-stochastic steady state values, and therefore, precautionary savings due to volatility are ignored. This is an important issue in this paper, since we want to analyze the economic impact of energy price fluctuations. Thus, we solve the model using both a first-order and a second-order approximation technique, and compare the results. We do not find significant differences when a higher order approximation is used. A further discussion of the accuracy of this solution method can be found in Arouba et al (2006).

## 4 The welfare cost of energy insecurity

In this section we propose a measure of the welfare cost of energy insecurity. As mentioned above, we associate energy insecurity to energy price fluctuations. We apply this measure to the Spanish economy and calculate the welfare cost caused by energy price fluctuations from 1970 to 2007. We use observed real data in this period to evaluate the consequences of energy price volatility in the economy.

We construct our measure comparing two economies: an economy where energy price fluctuates (as observed in the real data) and an economy where energy price is constant and equal to the mean value of the observed energy price (Figure 1). The average energy price and the starting initial conditions are the same in both economies. Our measure of energy insecurity relates the difference between the expected intertemporal utility of the representative agent in this two economies. To obtain the measure we derive the second-order approximation of expected utility around the steady state,

$$\begin{aligned}
 E[U(c_t, eh_t, n_t)] &= U(c_{ss}, eh_{ss}, n_{ss}) + \\
 &\left( \frac{\partial U}{\partial c_t} \Big|_{c_{ss}} \frac{\partial U}{\partial eh_t} \Big|_{eh_{ss}} \frac{\partial U}{\partial n_t} \Big|_{n_{ss}} \right) E \begin{pmatrix} c_t - c_{ss} \\ eh_t - eh_{ss} \\ n_t - n_{ss} \end{pmatrix} + \\
 &1/2 \left( \frac{\partial^2 U}{\partial c_t^2} \Big|_{c_{ss}} \frac{\partial^2 U}{\partial eh_t^2} \Big|_{eh_{ss}} \frac{\partial^2 U}{\partial n_t^2} \Big|_{n_{ss}} \right) E \begin{pmatrix} (c_t - c_{ss})^2 \\ (eh_t - eh_{ss})^2 \\ (n_t - n_{ss})^2 \end{pmatrix}
 \end{aligned} \tag{15}$$

Notice that  $E(c_t) = c_{ss}$ ,  $E(eh_t) = eh_{ss}$ ,  $E(n_t) = n_{ss}$ ,  $E(c_t - c_{ss})^2 = Var(c_t)$ ,  $E(c_t - c_{ss})^2 = Var(c_t)$  and  $E(c_t - c_{ss})^2 = Var(c_t)$ . Therefore, from equation XX, we get

$$D = U(c_{ss}, eh_{ss}, n_{ss}) - E[U(c_t, eh_t, n_t)] = -1/2 \left( \frac{\partial^2 U}{\partial c_t^2} \Big|_{c_{ss}} \text{Var}(c_t) + \frac{\partial^2 U}{\partial n_t^2} \Big|_{n_{ss}} \text{Var}(eh_t) + \frac{\partial^2 U}{\partial eh_t^2} \Big|_{eh_{ss}} \text{Var}(n_t) \right) \quad (16)$$

Where  $D$  is the difference between the utility in an economy without and with fluctuations. However this value is not very meaningful, since it depends on the size of the economy. Hence, we construct our measure as the percentage increase in non-energy consumption required to leave households indifferent between an economy with energy price fluctuations and an economy with a perfectly smooth price path. Thus, the measure we propose is given by

$$U^B(c_{ss}, eh_{ss}, n_{ss}) = E[U^A(c_t(1+x), eh_t, n_t)]. \quad (17)$$

Where  $x$  is the percentage consumption increase needed to equalize both utilities. Finally we express the welfare cost as a percentage of the GDP. Therefore our measure is obtained from the following expression:

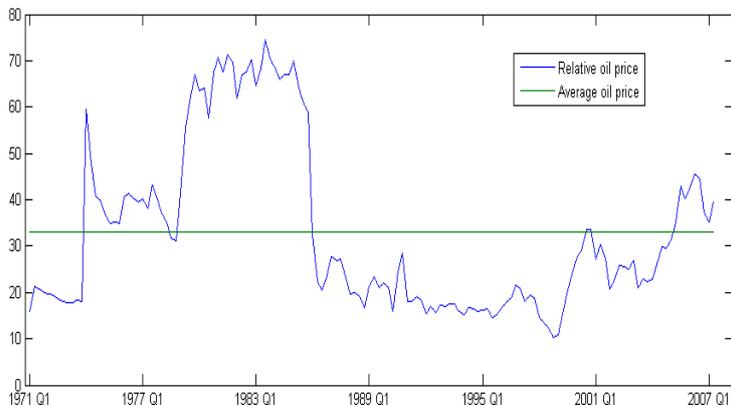
$$WC = x \frac{c_{ss}}{y_{ss}}, \quad (18)$$

Where WC is the percentage increase in the GDP needed to make households indifferent between an economy with and without energy price fluctuations.

#### 4.1 Numerical results

As mentioned before, we apply the measure to the Spanish economy. The objective is to estimate the cost of energy price fluctuations between 1970 and 2007. We use real data and, thus, the economy with fluctuations is simulated using observed energy prices.

Figure 1: Relative oil price (€2000)



Notice that we use the relative energy price expressed in euros (2000€). Consequently, there are three possible sources for fluctuations: energy price, inflation rate and euro-dollar exchange rate. Even if the energy price is constant the relative price can fluctuate. First, a decline in the price of other consumer goods implies an increase in the relative price of energy. And second, even if the energy price in dollars does not change, a depreciation of the euro leads to an increase in the relative energy price in euros. In this paper, we do not differentiate between sources of fluctuations. Therefore, when computing the welfare cost of energy price fluctuations, these can also be caused by fluctuations in inflation and exchange rates.

Table 2 summarizes the welfare results of energy price fluctuations. We present the results under different scenarios and, as mentioned before, we solve the model using a first-order and second-order approximation method.

In our benchmark model, the welfare cost of energy insecurity is 0.84% of the average consumption in terms of GDP. This result implies that households would be willing to give up 0.84% of consumption in terms of GDP to avoid fluctuations in energy prices. In other words, in absence of energy price

fluctuations, the households utility would increase 0.84% in terms of the average consumption. Notice the difference in the results when the model is solved using a first-order approximation method. In this case, the welfare loss is 0.59%. As argued before, a first-order approximation method does not account for precautionary savings. Actually, non-energy consumption level at the steady state is 0.11% higher in an economy without fluctuations. Likewise, energy consumption is 0.08% higher and labor supply is 0.08% lower. This is because uncertainty leads consumers to protect themselves against possible price increases in the future. Hence, in a first-order approximation method, which does not account for precautionary savings, the welfare loss of price fluctuations is lower.

In our benchmark model both households and firms demand energy and, therefore, energy price fluctuations are transmitted through these two channels to the main variables of the economy. However, most of the welfare loss is generated through energy consumption by households. In an economy in which energy is only used for production ( $\gamma = 0$ ), the welfare cost of energy price fluctuations is around 0.026%. Notice that our model replicates an economy without rigidities, and therefore, fluctuations in energy prices do not have a significant impact on firms. In absence of capital-energy complementarities (Atkeson and Kehoe, 1999) and endogenous capital utilization (Finn, 2000), firms can quickly adjust to price shocks.

In absence of energy consumption, the framework is similar to Lucas (1987), and thus, we obtain similar results. Energy price fluctuations generate small cycles on real output and the final effect on the main variables of the economy is also very small, consequently, the welfare loss is insignificant. Therefore it is necessary to highlight the importance of energy consumption by households as a determining factor in the welfare loss of energy price fluctuations.

Table 2: Welfare Cost of Energy Insecurity

	Benchmark model		$\gamma = 0$	
	1st Order	2nd Order	1st Order	2nd Order
Benchmark model	0.59%	0.84%	0.025%	0.026%
$\sigma = 0$	0.58%	0.83%	0.022%	0.023%
$\sigma = -5$	0.64%	0.91%	0.041%	0.042%
$1/(1 - \alpha) = 0.5$	1.35%	1.59%	-	-
$1/(1 - \alpha) = 1$	0.42%	0.65%	-	-
$1/(1 + \nu) = 0.5$	1.17%	1.47%	0.48%	0.50%
$1/(1 + \nu) = 1$	0.54%	0.77%	0.001%	0.001%

## 4.2 Sensitivity analysis

We perform sensitivity analysis for the key parameters of the model. Apart from the benchmark value of  $\sigma = -1$ , we calculate the welfare cost when households are risk neutral  $\sigma = 0$  and when they are more risk averse  $\sigma = -5$ . Risk neutrality does not reduce much the results; in this scenario, the welfare cost of energy price fluctuations is 0.83% of the average consumption in terms of output. On the other hand, when consumers are more risk adverse, volatility in energy prices can cause a welfare loss of 0.91% of the average consumption.

We find that the elasticity of substitution between energy and both non-energy goods (households) and capital (firms) has a higher impact than the risk adverse parameter. The benchmark value of  $\alpha = 0.18$  corresponds to an elasticity of substitution between energy and non-energy consumption of 0.85. We also pick a smaller elasticity of 0.5 which corresponds to  $\alpha = -1$ . In this case, the welfare cost of fluctuations in the energy price is 1.59%. This is an expected result, since price volatility should have a higher impact on the welfare when it is more difficult to replace one consumption good for

another. Likewise, we pick an elasticity of 1 which corresponds to  $\alpha = 0$ . As expected, when it is easier to replace energy for non-energy consumption, the welfare cost of fluctuations is lower.

The elasticity of substitution between energy and capital also has an important effect on the welfare loss. In addition to the benchmark value of 0.76 ( $\nu = 0.32$ ), we pick a lower elasticity of 0.5 ( $\nu = 1$ ) and a higher elasticity of 1 ( $\nu = 0$ ). We find that the lower is the elasticity the higher is the welfare loss caused by fluctuations in energy price. When, it is more difficult to replace energy for capital, energy price volatility leads to a welfare loss of 1.47%. On the other hand, in a scenario with a higher value for the elasticity parameter, the welfare loss is around 0.77%.

The sensitivity analysis shows the importance of the elasticity of substitution between energy and both non-energy goods and capital in the proposed measure for the welfare costs of energy insecurity. In contrast to the risk adverse parameter, changes on the elasticity of substitution have significant effects on the results. Thus, the ability to facilitate energy substitutability for both households and firms is crucial to reduce the costs of energy insecurity.

## 5 Conclusion

In recent years, energy security has become once again a priority of energy policy. The high volatility and uncertainty on the energy markets has increased the interest in this dimension of the energy policy. The literature has put much effort into trying to define and measure energy security. Nevertheless, little is known about its economic consequences.

The aim of this paper is to provide a macroeconomic measure of the welfare cost of energy insecurity. We relate energy security to energy price volatility and, therefore, quantify the welfare cost caused by the fluctuations in the energy price. We focus on the price dimension of energy security.

Although this may be seen as a limitation in our measure, we believe that most of the energy risks are reflected in the final price. Thus, analyzing the fluctuations in the price of energy is a good way to quantify energy security.

We use a standard DSGE model which is calibrated for the Spanish economy. In the model, energy is a consumption good for households and a production input for firms. Thus, energy price fluctuations affect households' utility in two ways. First, energy enters utility function as a consumption good, and therefore, energy price fluctuations have a direct impact on energy consumption and, consequently, on households' welfare. Second, firms use energy for production and, thus, the fluctuations in the energy price lead to increase the volatility of output, leisure and non-energy consumption, which affect ultimately households' welfare.

We find that the fluctuations in the energy price have a significant impact on households' welfare. In the last 30 years, the welfare loss caused by energy price volatility in Spain has been around 0.8% of average consumption in terms of GDP. This is an important result that reveals the economic consequences of energy insecurity. In particular, we show the significant impact on households' welfare due to fluctuations in energy prices. This result should make clear the importance of energy security when planning an energy policy. In addition to the political and social costs, energy insecurity causes a significant economic cost.

Our results show that energy price fluctuations mainly affect utility through household energy consumption. They increase the volatility in energy consumption which causes a decline in households' welfare. On the other hand, energy price fluctuations have not a significant impact on the volatility of output, non-energy consumption and leisure. Consequently, in an economy in which energy is only used for production, the welfare loss caused by price fluctuations is much lower.

The sensitivity analysis shows the importance of the elasticity of substi-

tution between energy and both non-energy consumption goods and capital. The welfare cost of energy price fluctuations is highly dependent on how difficult it is to replace energy with non-energy consumption. Likewise, when firms find harder to substitute energy with capital, the welfare loss due to energy price fluctuations is much higher.

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