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Corrado Andini*, Ricardo Cabral** and José Eusébio Santos***

ABSTRACT

Policy makers are increasingly supporting the development of renewable electricity power generation projects not only for environmental concerns but also for economic reasons. Several studies have indeed documented that renewable electricity can be a viable economic alternative to electricity power generation based on non-renewable sources. Yet, most of the existing studies are based on microeconomic cost-benefit analyses which disregard the existence of large macroeconomic effects. This paper develops a novel method to evaluate the macroeconomic impact of renewable electricity power generation projects. Economic theory is used to identify the potential effects of these projects on the vector of macroeconomic variables affected by their implementation. A structural vector autoregression model is thus estimated using a novel dataset of quarterly macroeconomic and energy data for Portugal. The estimated impulse-response functions suggest that renewable electricity power generation projects have positive effects on real economic growth in the medium run, through both the investment and the operations phases. Import substitution is the key driver of the overall positive impact.

JEL classification: C32, E17, Q43

Keywords: renewable energy, macroeconomic impact, structural VAR

* University of Madeira, CEEAplA, IZA and GLO

** University of Madeira, CEEAplA and IPP

*** University of Madeira

Affiliation details

University of Madeira, Campus da Penteada, 9000-390 Funchal, Portugal

Centre of Applied Economic Studies of the Atlantic (CEEAplA), 9501-801 Ponta Delgada, Portugal

Institute for the Study of Labor (IZA), D-53072 Bonn, Germany

Institute of Public Policy (IPP) Thomas Jefferson - Correia da Serra, 1249-078, Lisboa, Portugal

Global Labor Organization (GLO), International network

Corresponding author

Corrado Andini E-mail: andini@uma.pt Tel.: +351 291 705 053

University of Madeira, Campus da Penteada, 9000-390 Funchal, Portugal

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1. Introduction

1.1 Motivation

Recent years have seen a growing interest in the development of power generation projects based on renewable energy sources. This is in large part explained by concerns regarding the environmental impact of carbon-based energy sources and of nuclear power. Particularly, the European Union renewable energy targets, carbon-dioxide taxes, renewable energy subsidies and price regulation, defined in response to the Kyoto accord, have been key factors in the promotion of renewable electricity power generation (REPG) projects.

In addition to the positive environmental externalities, the widespread use of renewable energy sources can also have important macroeconomic effects. Electricity production based on endogenous renewable sources can contribute to important elements of economic development through its impact on gross domestic product (GDP), unemployment and balance of trade, for example. An analysis of the macroeconomic impact of REPG projects is therefore an indispensable basis for strategic decisions aiming at the long-term promotion of sustainable development.

In this paper, we estimate the macroeconomic effects of using renewable rather than non-renewable energy sources in electricity power generation, exploring a novel dataset of macroeconomic and energy data for Portugal. The analysis allows us to investigate to what extent renewable electricity projects have positive macroeconomic effects.

The key idea of this paper, namely the import-substitution hypothesis, is summarized in Figure 1. Each dot represents the amount of net energy imports associated with total non-renewable (upper graph) and total renewable (lower graph) electricity production, in each quarter between 1988Q1 and 2015Q4. The lines represent how net energy imports change when electricity production increases, allowing for the relation to be non-linear. As one would reasonably expect, the net imports of energy are more sensitive to non-renewable than to renewable electricity production because the estimated elasticity is higher (1.669 vs. 0.591). The 1.669 estimated elasticity means that, when there is a decrease (increase) in the non-renewable electricity production by one percent, net energy imports decrease (increase) by 1.669 percent (Figure 1a). The 0.591 estimated elasticity means that, when there is an increase (decrease) in the renewable electricity production by one percent, net energy imports increase by 0.591 percent (Figure 1b). Thus, an increase in the renewable share of electricity production (through one-percent *reduction* in non-renewable production and one-percent *increase* in renewable production) is likely to reduce the net imports of energy (by 1.078 percent), producing positive macroeconomic effects.

Of course, such an important conclusion cannot be based on two simple regressions like those presented in Figure 1. This is why this paper estimates a multiple-equation macroeconomic model based on a structural vector autoregression (SVAR) approach.

If our main conclusion holds, then the microeconomic internal rate of return of REPG projects used in project-finance analyses (Owens, 2002; Chang, 2013) provides an estimate of the economic return of a project that is too low, given that it does not reflect the macroeconomic returns of REPG projects, namely the additional income and economic activity that are generated in the country where the project is implemented. It may well be the case that, while from a strict microeconomic perspective some REPG projects may display worse economic returns than comparable non-renewable power generation projects, the same REPG projects may offer superior economic returns in macroeconomic terms.

There is relatively little research on the macroeconomic effects of renewable electricity projects (Riddel and Schwer, 2003; Weisser, 2004; Kammen et al., 2006; Awerbuch and Sauter, 2006; Awerbuch, 2006; Markandya et al., 2016). In particular, in only in a few instances, does the existing literature explicitly consider the macroeconomic effect of using renewable endogenous sources rather than energy imports, and typically this issue is not analyzed in sufficient detail (Riddel and Schwer, 2003). This paper extends the existing literature by further developing the import-substitution hypothesis, by proposing a theoretical model for predicting the macroeconomic effects of REPG projects, and by estimating the model with a novel Portuguese dataset.

1.2 Related literature

Environmental concerns as well as periods, in the recent past, of rapid growth and volatility of crude oil prices have spurred renewed interest on the further exploitation of renewable energy sources. Partly as a consequence, the economic literature on renewable electricity projects and policies has grown.

1.2.1 Economic issues

A few research papers address the issue of the possible macroeconomic effects of REPG projects, which is the focus of this paper. For example, Riddel and Schwer (2003) evaluate the impact on Gross State Product and employment of switching away from thermoelectric generation towards renewable electricity generation using Nevada's endogenous resources.

Other studies focus on the net employment impact of the transition from fossil fuel-based economy to an economy based on renewable energy sources. The common feature of these studies is that they consider not only the positive impacts of the transition on the labor market but also the possible job losses in the coal and natural gas industry. For instance, Kammen et al. (2006) review 13 studies that analyze the job creation record of the renewable energy industry, all of which report a significant net positive impact on employment.

Similar net effects are found in studies authored by Lehr et al. (2008), Wei et al. (2010), Lehr et al. (2012) and Markandya et al. (2016). However, Cameron and van der Zwaan (2015) suggest that, from approximately 70 studies published over the past decade, there is a considerable ambivalence about the effects on job creation, both across and within publications. They argue that, based on the current evidence, it is doubtful whether job creation should be used as the main argument for further investment in renewable electricity generation. According to them, the focus should probably be on the benefits offered by these technologies in terms of energy independence, greenhouse gas abatement and air quality.

Finally, there is a large literature on the so-called "oil-shock effect" that is also of relevance for our analysis for two reasons (Hamilton, 1983; Hamilton, 2008; Jones et al., 2004; Awerbuch and Sauter, 2006; Aguiar-Conraria and Wen, 2007). The first is the use of econometric methods based on time-series data. The second is that the 1973 oil-price shock resulted in an exogenous increase in the nominal expenditure on oil imports. The latter caused a substantial reduction in real GDP through a strong multiplier effect (Aguiar-Conraria and Wen, 2007). Related studies include Weisser (2004), Weidenmier et al. (2008), and Rentschler (2013).

We contribute to the above literature by measuring the macroeconomic effects of REPG projects on a number of different outcomes (e.g., growth, unemployment, inflation, and so on) using a structural vector autoregression (SVAR) methodology. Our macroeconomic impacts are measured using a model which is less opaque than the input-output models typically used in the previous studies, given the considerable number of assumptions that input-output models require to reach a high level of aggregation. Further, we contribute by adding evidence based on time-series data, in the same vein as the "oil-shock effect" literature, whereas input-output studies are typically based on cross-sectional data. In line with the "oil-shock effect" literature, renewable electricity projects are promoted in this paper as a form of reducing nominal expenditure with imports of oil, and of substituting this expenditure by endogenous energy sources.

1.2.2 Policy issues

A separate branch of literature is concerned with the different policies used to promote renewable electricity generation. Governments can use several mechanisms to support renewables, including changes in taxation and regulatory law of conventional sources (e.g., pollution taxes, emission cap regulations), direct financial support (e.g., grants, tax credits, low interest loans), indirect support (e.g., R&D support, training, funding of demonstrations projects), and the Renewable Portfolio Standard (RPS). Given that a central issue for most governments is the possibility of achieving the renewable targets at the lowest possible cost, a considerable amount of the literature compares the relative efficiency of the different incentive schemes.

For example, Menanteau et al. (2003) compare the effectiveness of price-based approaches with quantity-based approaches. They find that quantity-based instruments (e.g., output targets or quotas) have the advantage of minimizing policy costs. In contrast, price-based instruments may result in divergences between expected and actual renewable electricity output and have non-quantifiable policy costs.

Similar studies include Palmer and Burtraw (2005), Berry and Jaccard (2001), Wiser and Barbose (2008), Dong (2012), Kwon (2015), Matysek and Fisher (2007), Schaffer and Bernauer (2014), Lehmann and Gawel (2013) and also a report of the Economic Affairs Committee of the House of Lords prepared for the British Government (HL, 2008).

We contribute to this literature by demonstrating the remarkable macroeconomic advantages in the medium term associated with the expansion of renewable electricity supply. The concerns expressed in the literature regarding the resulting costs of raising renewable electricity output are lessened with the evidence on benefits presented here.

1.2.3 Technical issues

A related strand of literature (Neuhoff, 2005; Duić and Carvalho, 2004; among others) focuses on the feasibility and obstacles towards achieving much higher shares of total electricity consumption from renewable energy sources, i.e. large scale renewable deployment.

In particular, Neuhoff (2005) argues that renewables could satisfy a much larger share of global energy demand, with clear benefits in terms of security and environment. However, large scale renewable electricity generation faces substantial technical and economic challenges. Thus, the economic policy framework would have to be changed to create the appropriate incentives for investment in renewable electricity generation capacity and for investment in the R&D required to overcome the still substantial technical challenges.

Duić and Carvalho (2004) develop a case study of how the share of renewable electricity generation could be increased to 100% of total consumption in the island of Porto Santo (Madeira, Portugal). They argue that 100% renewable share would be a technically feasible target, albeit one with high costs. This occurs due to the need to convert wind energy to hydrogen through electrolysis, store the hydrogen, and then use fuel cells to meet demand for electricity when, due to weather conditions, wind electricity generation is low.

Our contribution to this literature branch is limited, as this paper does not enter into technical questions about how it would be possible to increase the renewable energy production. We just assume that, after an investment phase in physical renewable electricity power generation plants, the country is able to increase the share of renewable electricity in total production.

2. Materials and methods

2.1 Theoretical model

The theoretical model to evaluate the macroeconomic effects of REPG projects proposed in this paper is as follows:

(1) $$g_{GDP} = \alpha_1(g_{IND}) - \alpha_2(g_{NEI})$$ (GDP growth equation)

Real GDP growth (on the left in Eq. 1) responds to real aggregate demand growth (on the right), i.e. to the real growth in internal demand and to the real growth in net imports (see Appendix A).

(2) $$g_{IND} = \alpha_3(g_{PRC}) + \alpha_4(g_{PUC}) + \alpha_5(g_{INV})$$

(3) $$g_{NEI} = \alpha_6(g_{IMP}) - \alpha_7(g_{EXP})$$

The real growth in internal demand (on the left in Eq. 2) is driven by the real growth in private consumption, public consumption and gross investment, while the growth rate of net imports (on the left in Eq. 3) responds to real growth in imports and exports.[1]

(4) $$\pi = \alpha_8 g_{WAG} - \alpha_9 g_{PRO} + \alpha_{10} i_{BND} + \alpha_{11} \pi_{ELE} + \alpha_{12} \pi_{OIL} + \alpha_{13} \Delta_{MKP}$$

(Inflation equation under mark-up pricing)

Inflation (on the left in Eq. 4) is driven by nominal wage growth, real labour productivity growth, the nominal cost of capital (proxied by the nominal interest rate on 10-year government bonds), the growth rate of the electricity consumption price (electricity consumption price inflation), the growth rate of the oil price (oil price inflation), and the variation of the profit mark-up (Lavoie, 2015).

(5) $$i_{BND} = \alpha_{14} i^{f}_{BND} + \alpha_{15} E(g_{EXC}) + \alpha_{16} (\pi - \pi^{n}) + \alpha_{17} (g_{GDP} - g^{n}_{GDP})$$

(Augmented Taylor rule)

The nominal interest rate (on the left in Eq. 5) responds, among other things, to a reference interest rate abroad, to the expected exchange-rate depreciation and to deviations of inflation and GDP growth from their respective natural rates (see Taylor, 1993).

(6) $$u - u^{n} = \alpha_{18} (g_{GDP} - g^{n}_{GDP})$$ (Okun law)

(7) $$g_{WAG} = -\alpha_{19} (u - u^{n})$$ (Phillips curve)

[1] Our decomposition of real GDP growth by major demand components is inspired by the U.S. Bureau of Labor Statistics decomposition available at: https://www.bls.gov/emp/ep_table_402.htm

The unemployment rate (on the left in Eq. 6) decreases as real GDP growth gets higher (see Okun, 1970), possibly pushing nominal wage growth (on the left in Eq. 7) and inflation up (see Phillips, 1958).

(8) $$g_{PRC} = \alpha_{20} g_{GDP} - \alpha_{21}(i_{BND} - \pi)$$ (Private consumption growth equation)

The growth rate of private consumption (on the left in Eq. 8) responds, among other factors, positively to real GDP growth (g_{GDP}), because of the marginal propensity to consume, and negatively to the real cost of capital ($i_{BND} - \pi$), as higher real cost of capital means lower growth in real consumption credit (see Carroll and Summers, 1991).

(9) $$g_{INV} = \alpha_{22} g_{GDP} - \alpha_{23}(i_{BND} - \pi)$$ (Investment growth equation)

The growth rate of gross investment (on the left in Eq. 9) responds similarly to real GDP growth and real cost of capital because of the accelerator principle and the standard theory of investment borrowing. The principle suggests that higher real GDP growth induces higher expected sales growth and thus higher real growth of investment in production capacity. The borrowing theory suggests that higher real cost of capital induces lower real investment growth (see Knox, 1952; Jorgenson, 1963).

(10) $$g_{EXP} = \alpha_{24} g^{f}_{GDP} + \alpha_{25}(\pi^{f} - \pi) + \alpha_{26} g_{EXC}$$ (Export growth equation)

Real export growth (on the left in Eq. 10) is a positive function of real GDP growth abroad (proxied by the real GDP growth in Spain), nominal exchange rate devaluation, and decreases with domestic inflation (see Blanchard, 2000).

(11) $$g_{IMP} = \alpha_{27} g_{GDP} - \alpha_{28}(\pi^f - \pi) - \alpha_{29} g_{EXC}$$ (Import growth equation)

Real import growth (on the left in Eq. 11) is a positive function of real domestic GDP growth and domestic inflation, and decreases with nominal exchange rate devaluation (see Blanchard, 2000).

There are, of course, *other factors* playing a role in each of the equations listed above, but we do not explicitly model these factors to keep the presentation of the model as simple as possible. Among the additional factors affecting the investment growth equation, we include the growth of investment in renewable energy production capacity.

In this framework, we analyze two types of shocks:

- A one-time increase in the real growth of gross investment in renewable energy production capacity;
- A permanent increase in the renewable share of electricity production.

The first shock is expected to increase the real growth of gross investment ($g_{INV} \uparrow$) with multiplicative positive impacts on real GDP and consumption growth, thus decreasing the unemployment rate. Since the shock is temporary, its effects are likely to disappear over time.

The second shock is expected to decrease the net energy imports as share of GDP, thus positively affecting real GDP growth through a reduction of the net import elasticity ($\alpha_2 \downarrow$). The Appendix A shows why the coefficient α_2 responds to net energy imports as share of GDP.

The expected drawback of the second shock is that, since renewable electricity has higher unit cost of production than non-renewable electricity, the growth rate of the electricity consumption price is likely to increase, boosting inflation. As a result of higher real GDP growth, the unemployment rate is likely to fall, boosting nominal wage growth and inflation.

The next section examines the phases of implementation of REPG projects.

2.2 The implementation phases of REPG projects

The macroeconomic effect of REPG projects has two separate components. The first is related to the investment phase in REPG capacity, where the additional capacity is built up. The second is associated with the operations phase, where there is a switch from non-renewable to renewable electricity production.

2.2.1 Investment phase: building REPG capacity

As we have seen, a one-time increase in the growth rate of gross investment in REPG capacity is expected to positively affect the aggregate demand growth, pushing domestic GDP growth up. This has a series of consequences, including a decrease in the unemployment rate. However, all these effects are likely to disappear over time. In the empirical analysis, we will just comment on the macroeconomic variables that are more relevant for the aim of the study in a medium-run perspective, i.e. 20 quarters.

2.2.2 Operations phase: increasing the renewable share

As stressed before, a permanent increase in the share of renewable electricity production in the medium run is likely to increase real GDP growth, by reducing the net imports of energy. Of course, we should not expect a reduction on the real growth rate of total imports because total imports are responsive to domestic GDP increases. What we should instead expect is a decrease in the unemployment rate and an increase in inflation, based on our theoretical model. Again, the empirical analysis will have a medium-run horizon.

2.3 Dataset

The empirical analysis presented in this paper is based on a dataset of macroeconomic and energy variables specifically compiled for this article.

2.3.1 Macroeconomic data

The national accounts and labour market data are available from Banco de Portugal on a quarterly basis, since the first quarter of 1977.[2] These data have been widely used in macroeconomic analyses for Portugal (for a macroeconomic analysis, see for instance Andini, 2008; for a detailed description of the data, see Castro and Esteves, 2004; for an updated description, see Cardoso and Sequeira, 2015).

GDP data for Spain are from the Instituto Nacional de Estadística, the Spanish statistical office. The data on oil price, nominal exchange rate and interest rate are provided by Dow Jones & Company, Federal Reserve Bank of St. Luis and International Monetary Fund, respectively. While oil prices and exchange-rate data are publically available, the

[2] These data can be downloaded at https://www.bportugal.pt/sites/default/files/anexos/series/series_trimestrais_2016_p.xlsx

interest rate is taken from the DVD edition of the International Financial Statistics database (May 2015).

2.3.2 Energy data

Data on electricity output and consumption are available from Redes Energéticas Nacionais (REN) in monthly format since January 1980. Data on energy and fuel imports with and without electricity are available from Instituto Nacional de Estatística (INE) in monthly format since January 1988. All monthly data have been transformed into quarterly data using standard procedures.

In particular, REN compiles electricity produced and consumed through the national electric grid. It classifies production according to energy sources. Electricity production is classified as belonging either to the ordinary regime or to the special regime (PRE). The special regime designates small-scale electricity production from endogenous, renewable or non-renewable, energy sources. Most of PRE renewable output is derived from wind energy, though PRE renewable production can also include output from mini-hydroelectric dams and solar electricity plants.[3] The ordinary regime refers to all other electricity production including large hydroelectric dams. The ordinary regime accounts for 56.6% of total electricity consumption in 2015. The share of hydroelectric electricity production in the ordinary regime is 18.0% of total electricity consumption.[4]

Figure 2 suggests that Portugal's share of renewable electricity output has historically been highly seasonable and volatile as a result of the dependence on large

[3] The PRE was established by DL 189/1988. It has since been complemented by DL 313/1995, DL 168/1999, DL 312/2001, DL 339-C/2001, DL 33A/2005, DL 29/2006, DL 172/2006, and DL 225/2007. The PRE allows independent and qualified producers to sell electricity at specified tariffs to commercial operators.

[4] Authors' calculations using REN monthly statistics (accumulated values in December 2015). The data are available at http://www.centrodeinformacao.ren.pt/PT/InformacaoExploracao/Paginas/EstatisticaMensal.aspx

hydroelectric dams.[5] In years and quarters with more rain, hydroelectric output rises. Hence, the renewable electricity share of total electricity production rises. Yet, in recent years, thanks to growing share of wind power generation, the share of renewable electricity output has increased and the level of renewable electricity output has become more stable.

2.3.3 Overview and summary statistics

Figure 3 describes the 18 variables used to estimate the econometric model that we will present in the next section. Descriptive statistics for each variable are provided in Table 1. The whole dataset is downloadable from the corresponding author's website.[6] Rather than discussing each variable individually, it is important to briefly present the macroeconomic and energy framework of the country that our study focuses on.

Our data usually cover all quarters between 1977 and 2015. During this period, the growth rate of real GDP in Portugal has been around 0.5% (RGG). Despite this relatively low growth, the Portuguese labor market has only experienced high unemployment rates in recent years. On average, the share of the labor force looking for a job has been around 7.3% (UNR), mainly as a result of the increase occurred after the country joined the euro-area (see Figure 3).

In the years covered by our sample, both private consumption and public consumption have grown faster than GDP in real terms, at rates of 0.6% (RGPRC) and 0.7% (RGPUC) respectively. Gross capital formation, including both private and public investment expenditures, has grown slower than GDP in real terms, at a rate of 0.4% (RGGI) on average. A slightly positive contribution to GDP growth has come from the

[5] Authors' calculations based on REN monthly data obtained by e-mail on 18 February 2009. The data have been requested at comunicacao@ren.pt and are updated until January 2009. Data from January 2007 onwards are at http://www.centrodeinformacao.ren.pt/PT/InformacaoExploracao/Paginas/EstatisticaMensal.aspx

[6] The link is http://www.uma.pt/andini/docs/suppmat.zip

external sector where real exports have grown faster than real imports, at average rates of 1.7% (RGE) and 1.6% (RGI) respectively.

Portugal has historically had a large trade deficit. On average, the quarterly current account deficit has been 7.2% of GDP between 1977 and 2015, with peaks up to 19.5%.[7] Net energy imports have always represented a large share of the overall trade deficit, due to the lack of primary energy sources in the Portuguese territory (oil, natural gas, and coal). On average, the quarterly energy balance deficit has been 2.6% of GDP between 1988 and 2015, with peaks up to 5.2% (NEISG).[8] It follows that reducing net energy imports as share of GDP can be seen as a primary goal for reducing net total imports as share of GDP. This paper will argue that such a goal can be achieved by increasing the renewable share of electricity production.

2.4 Econometric model

As is well known, the estimation of the type of theoretical model put forward in Section 2.1 must address severe endogeneity problems due to simultaneity and reserve causality among the variables of interest. These problems can be addressed by estimating a structural vector autoregression (SVAR) model, which is commonly used for forecasting systems of interrelated time series and for analyzing the dynamic impact of exogenous shocks on the variables of the system (Favero, 2001).

Let y_t be the vector of all the 18 variables presented in Figure 3. The links among all the variables in our dataset can be modelled using a SVAR model of the following type:

[7] Authors' calculations based on quarterly data from Banco de Portugal. The data are available for download at https://www.bportugal.pt/sites/default/files/anexos/series/series_trimestrais_2016_p.xlsx

[8] Authors' calculations based on INE data provided by e-mail on 20 January 2017. The data have been obtained from info@ine.pt and are updated until December 2016. The request should specify the following sequence: Comércio Internacional de Bens (CI) => Classificação por Grandes Categorias Económicas (CGCE) => Combustíveis e Lubrificantes (Código 3).

(12) $$y_t = c + A_0 y_t + \sum_{i=1}^{p} A_i y_{t-i} + z_t$$

where the matrix A_0 takes into account all the contemporaneous conditional correlations among the variables in the vector y_t, including those (the *alpha* coefficients) discussed in our theoretical model (for instance, g_{GDP} is affected by g_{PRC} in the *GDP growth equation* but it also affects g_{PRC} in the *Private consumption growth equation*).

Since the above model cannot be consistently estimated by ordinary least squares (OLS), we estimate it in the so-called reduced form, i.e.:

(13) $$y_t = (I - A_0)^{-1} c + \sum_{i=1}^{p} (I - A_0)^{-1} A_i y_{t-i} + (I - A_0)^{-1} z_t$$

or

(14) $$y_t = \Phi_0 + \sum_{i=1}^{p} \Phi_i y_{t-i} + v_t$$

Several lag-length criteria suggest the estimation of a second-order reduced-form VAR, i.e. $p = 2$ in the above expression.

Note that $v_t = (I - A_0)^{-1} z_t$ is the equation linking the vector of the reduced-form residuals v to the vector of the structural shocks z. This equation is identified in this paper using the method developed by Pesaran and Shin (1998) which is characterized by the desirable feature that the shape of the structural impulse-response functions is independent of the variables' ordering in the vector y. The Appendix B discusses technical details about our empirical model.

Although the standard ADF unit-root test (Dickey and Fuller, 1979) is not passed by some variables in our dataset, we assume that all variables can be treated as generated by stationary stochastic processes as the standard ADF test is characterized by low power in relatively small samples, such as our sample. This view is partly supported by the results of the KPSS test (Kwiatkowski et al., 1992). In addition, the roots of the estimated reduced-form VAR lie inside the unit circle, meaning that model (14) satisfies the required stability condition.

The next section will comment on the structural impulse-response functions obtained after estimating model (14) and identifying the equation $v_t = (I - A_0)^{-1} z_t$ through the method of Pesaran and Shin (1998). The calculations are available for download from the corresponding author's website.[9] The analysis has been carried out using the commercial software EVIEWS 7.

3. Results

As referred in Section 2.2, REPG projects have two distinct types of phases: investment and operations. The objective of this section is to estimate the effects of REPG projects in both phases. Before proceeding to the results, it is worth stressing that all the estimated effects presented here are based on time-series analysis and therefore on information from past data. Future (unexpected) events may well affect the realization of the forecasts. Consider first the econometric results regarding the investment phase.

[9] The link is http://www.uma.pt/andini/docs/suppmat.zip

3.1 Investment phase: impulse-response functions

First of all, it should be noted that there is no historical series of national investment expenditure in REPG projects. Moreover, different types of renewable electricity projects (hydroelectric dams, wind turbines, solar power stations) are likely to have different effects, for example depending on the proportion of the expenditure that is satisfied through domestic suppliers or through imports.

To address the problem created by the lack of specific data, we use a proxy obtained as the interaction between the real growth rate of gross investment and the renewable share of electricity production. The logic is simple. An increase in the growth rate of investment in REPG capacity increases both the growth rate of gross investment and the renewable share of electricity production. It follows that their interaction (mathematical product) gets bigger.

As predicted by the theoretical model, the growth of investment in REPG infrastructure results in an increase in the real growth rates of both GDP and private consumption, while decreasing unemployment.

The effects are summarized in Figure 4 and can be interpreted as follows. A one-time 1.10% increase in the growth rate of investment in REPG capacity (one standard deviation in the structural innovations) generates a temporary positive effect on real GDP growth by 0.24% in the same quarter, which tends to disappear over time, being only 0.01% after 5 years (Figure 4.1). The growth rate of private consumption follows a similar pattern (Figure 4.2). However, the unemployment rate (which is a more persistent variable) decreases during the whole period reaching -0.23% in the last quarter (Figure 4.11).

In sum, we estimate a contemporaneous elasticity between growth of GDP and growth of investment in REPG capacity at 0.21 = 0.24/1.10 (or 21%). This suggests that the use of investment expenditure in REPG capacity to stimulate short-run GDP growth is warranted.

The effects on all the other variables in Figure 4 are consistent with what one should expect from the theory. They tend to disappear over time because a one-time increase in the growth rate of investment in REPG capacity (the growth rate deviates from its mean value in quarter 1 but reverts to its mean value from quarter 2 to 20) is unlikely to have permanent effects.

3.2 Operations phase: impulse-response functions

In this section, we present the macroeconomic effects of a permanent increase of 13.3% in the renewable share of electricity output (one standard deviation in the structural innovations). The effects are summarized in Figure 5.

As expected, there is a decrease in net imports of energy as share of GDP from the starting quarter to the final one, with a total reduction amounting to 1.35% after 5 years (Figure 5.8). This has the effect of reducing the net import elasticity and so increasing the real GDP growth by a total of 0.74% (Figure 5.1).

In sum, we estimate a medium-run elasticity between GDP growth and the renewable share of electricity output at roughly 0.06 = 0.74/13.3 (or 6%), suggesting that the substitution of non-renewables by renewables is warranted from a macroeconomic perspective.

It is also clear that the effect on the unemployment rate is positive, with an estimated reduction of 2.68% in five years (Figure 5.11). Again as expected, inflation is found to increase (Figure 5.10), mainly driven by the push in nominal wage growth (Figure 5.12) induced by the unemployment decline (Figure 5.11). Higher inflation and real growth also imply some increase in the cost of capital (Figure 5.17).

What is not expected is the little effect on the growth rate of the electricity consumption price (Figure 5.14), to the extent that renewable electricity has higher unit cost of production than non-renewable electricity.

Another unexpected result is the reduction in the growth rate of oil price (Figure 5.15), probably driven by the lower demand for oil imports. Note, however, that the confidence interval (in Figure 5.15) is compatible with absence of an effect on oil prices, which is a more reasonable outcome if we take into account the marginal impact of Portugal in the world trade of oil.

3.3 Summing up

The SVAR results suggest positive macroeconomic effects of the substitution of non-renewable by renewable electricity output. On the one hand, a transitory increase in the real growth rate of investment in REPG capacity produces positive short-run effects on real GDP growth (Figure 4.1) and positive medium-run effects on the unemployment rate (Figure 4.11). On the other hand, a permanent increase in the renewable share of electricity production reduces the net imports of energy (Figure 5.8) and increases GDP growth in the short and medium-run (Figure 5.1.), while decreasing unemployment (Figure 5.11). A side effect is higher inflation (Figure 5.10).

4. Conclusions

In this analysis, we have developed an approach to study whether REPG projects are valuable projects from a macroeconomic point of view. We have proposed a theoretical model to analyze the impact of REPG projects on a vector of macroeconomic outcomes. In addition, using a novel dataset of macroeconomic and energy data for Portugal, we have estimated a structural vector autoregression (SVAR). The results of our SVAR model suggest that both phases of implementation of REPG projects are beneficial for the economy. As for the investment phase, the benefits are transitory. As for the operations phase, they are permanent. However, both phases have positive effects on real GDP growth, though inflation levels get slightly higher. Higher GDP growth in the operations phase is driven by the reduction of net energy imports as share of GDP.

In sum, we have extended the existing literature by proposing a theoretical model for predicting the macroeconomic effects of REPG projects, by estimating the model with a novel Portuguese dataset, and by providing further support to the import-substitution hypothesis.

The macroeconomic approach proposed here complements and enhances standard microeconomic analyses based on project-finance indicators. When compared to other macroeconomic models, namely the input-output models used in previous studies, our model is less opaque given the considerable number of assumptions that input-output models require to reach a high level of aggregation. In addition, our evidence is based on time-series data whereas earlier input-output studies are typically based on cross-sectional data.

There are two main policy implications of our study. First, publicly-funded REPG projects can be an effective form of expansionary fiscal policy. Second, REPG projects can be used to target the development of specific local areas or country regions.

From a national point of view, the adoption of expansionary fiscal policies may result in the deterioration of the current-account balance, and thus may be unsustainable in the medium term. This analysis identifies a type of expansionary measure which does not necessarily worsen the net international investment position of the country, by reducing net energy imports as share of GDP.

From a local and regional perspective, governments are constantly in search of policy instruments to promote the economic development of specific target areas. This analysis shows that REPG projects can contribute to the achievement of local and regional policy goals, reducing unemployment and raising GDP growth in areas where these outcomes are mostly needed.

A limitation of our paper is that it examines only the tangible benefits of developing REPG projects. The intangible benefits of reducing air pollutants and climate changing emissions are nevertheless considerably important. If we take together the tangible and intangible benefits, REPG projects become clearly an attractive option for sustainable development, enriching the policy toolkit of governments.

Appendix A

National accounting suggests that GDP equals internal demand minus net imports, i.e.:

(A1) $$GDP = IND - NEI$$

By subtracting and dividing for lagged GDP at both sides we get:

(A2) $$\frac{GDP - GDP_{-1}}{GDP_{-1}} = \frac{IND - NEI - (IND_{-1} - NEI_{-1})}{GDP_{-1}}$$

which can be written as:

(A3) $$\frac{GDP - GDP_{-1}}{GDP_{-1}} = \frac{IND - IND_{-1}}{GDP_{-1}} - \frac{NEI - NEI_{-1}}{GDP_{-1}}$$

After some manipulation, we get the expression:

(A4) $$\frac{GDP - GDP_{-1}}{GDP_{-1}} = \left(\frac{IND_{-1}}{GDP_{-1}}\right)\frac{IND - IND_{-1}}{IND_{-1}} - \left(\frac{NEI_{-1}}{GDP_{-1}}\right)\frac{NEI - NEI_{-1}}{NEI_{-1}}$$

or

(A5) $$g_{GDP} = \alpha_1(g_{IND}) - \alpha_2(g_{NEI})$$

showing why the coefficient α_2 in our theoretical model responds to net imports as share of GDP, and thus to net imports of energy as share of GDP.

In short, one theoretical mechanism envisioned in this paper is that an increase in the renewable share of electricity production decreases net energy imports as share of GDP, which in turn reduces net total imports as share of GDP, which in turn reduces the coefficient α_2 and thus increases GDP growth.

Appendix B

To be more precise about what is done in SVAR estimation, let us consider a simple model where there are only two relevant variables $Y1$ and $Y2$, as in Andini (2006). The model allows for the existence of two-side causality between $Y1$ and $Y2$ since these variables are modelled as dynamic functions of each other, constant intercepts C and structural shocks Z, i.e.:

(B1) $$Y1_t = C_{Y1} + \sum_{i=1}^{p} \phi_i Y1_{t-i} + \sum_{i=0}^{p} \delta_i Y2_{t-i} + Z_{Y1t}$$

(B2) $$Y2_t = C_{Y2} + \sum_{i=1}^{p} \eta_i Y2_{t-i} + \sum_{i=0}^{p} \theta_i Y2_{t-i} + Z_{Y2t}$$

Note that the variance-covariance matrix of the Z disturbances is diagonal, meaning that the structural shocks are uncorrelated by assumption, i.e. they are exogenous.

The SVAR model formed by (B1) and (B2) can be written as follows:

(B3) $$y_t = c + A_0 y_t + \sum_{i=1}^{p} A_i y_{t-i} + z_t$$

where $y_t = \begin{bmatrix} Y1_t \\ Y2_t \end{bmatrix}$, $c = \begin{bmatrix} C_{Y1} \\ C_{Y2} \end{bmatrix}$, $A_0 = \begin{bmatrix} 0 & \delta_0 \\ \theta_0 & 0 \end{bmatrix}$, $A_i = \begin{bmatrix} \phi_i & \delta_i \\ \theta_i & \eta_i \end{bmatrix}$ for $i = 1,...,p$ and $z_t = \begin{bmatrix} Z_{Y1t} \\ Z_{Y2t} \end{bmatrix}$.

By simple algebra, we obtain the reduced-form VAR model, i.e.:

(B4) $$y_t = (I - A_0)^{-1} c + \sum_{i=1}^{p} (I - A_0)^{-1} A_i y_{t-i} + (I - A_0)^{-1} z_t$$

where $I - A_0 = \begin{bmatrix} 1 & -\delta_0 \\ -\theta_0 & 1 \end{bmatrix}$

To simplify notation, model (B4) can be re-written in the following form:

(B5) $$y_t = \Phi_0 + \sum_{i=1}^{p} \Phi_i y_{t-i} + v_t$$

where $v_t = Dz_t$ and $D = (I - A_0)^{-1}$. This implies that $E(v_t v_t') = DE(z_t z_t')D'$ where $E(z_t z_t')$ is a diagonal matrix by assumption.

More explicitly, we have:

(B6) $$\begin{bmatrix} V_{Y1t} \\ V_{Y2t} \end{bmatrix} = \frac{1}{1 - \delta_0 \theta_0} \begin{bmatrix} 1 & \delta_0 \\ \theta_0 & 1 \end{bmatrix} \begin{bmatrix} Z_{Y1t} \\ Z_{Y2t} \end{bmatrix}$$

or simply:

(B7) $$\begin{bmatrix} V_{Y1t} \\ V_{Y2t} \end{bmatrix} = \begin{bmatrix} D_{11} & D_{12} \\ D_{21} & D_{22} \end{bmatrix} \begin{bmatrix} Z_{Y1t} \\ Z_{Y2t} \end{bmatrix}$$

The ordinary least squares (OLS) estimator allows to obtain consistent estimates of the Φ's in model (5) and provides two time series of the reduced-form residuals, i.e. the V's. This allows the estimation of the variance-covariance matrix of the reduced-form residuals $E(v_t v_t')$.

By recursively solving model (B5), we get its infinite moving-average representation:

(B8) $$y_t = \bar{y} + \sum_{i=0}^{\infty} \Phi_i v_{t-i}$$

which can also be written as:

(B9) $$\begin{bmatrix} Y1_t \\ Y2_t \end{bmatrix}_t = \begin{bmatrix} \overline{Y1} \\ \overline{Y2} \end{bmatrix} + \sum_{i=0}^{\infty} \begin{bmatrix} \Phi_{11}(i) & \Phi_{12}(i) \\ \Phi_{21}(i) & \Phi_{22}(i) \end{bmatrix} \begin{bmatrix} V_{Y1t-i} \\ V_{Y2t-i} \end{bmatrix}$$

For example, let us consider the $Y1$ equation:

(B10) $$Y1_t = \overline{Y1} + \sum_{i=0}^{\infty} \Phi_{11}(i) V_{Y1t-i} + \sum_{i=0}^{\infty} \Phi_{12}(i) V_{Y2t-i}$$

Using this representation, we can easily see that, after n periods, the effect of V_{Y2t} on $Y1_{t+n}$ is $\Phi_{12}(n)$ while the total effect, from time 0 to time n, is $\sum_{i=0}^{n}\Phi_{12}(i)$.

However, we are interested in estimating the effect of Z_{Y2t} on $Y1_{t+n}$ because Z_{Y2} is an exogenous shock to $Y2$ while V_{Y2} is not. To obtain this effect, one should first note that $V_{Y2t} = D_{11}Z_{Y1t} + D_{12}Z_{Y1t}$ and that $V_{Y1t} = D_{21}Z_{Y1t} + D_{22}Z_{Y2t}$. Therefore, the $Y1$ equation can be written as:

(B11) $$Y1_t = \overline{Y1} + \sum_{i=0}^{\infty}\Phi_{11}(i)(D_{21}Z_{Y1t-i} + D_{22}Z_{Y2t-i}) + \sum_{i=0}^{\infty}\Phi_{12}(i)(D_{11}Z_{Y1t-i} + D_{12}Z_{Y2t-i})$$

So, in particular, we want to obtain $D_{12}\Phi_{12}(n) + D_{22}\Phi_{11}(n)$ and $\sum_{i=0}^{n}D_{12}\Phi_{12}(i) + \sum_{i=0}^{n}D_{22}\Phi_{11}(i)$.

The plot of $D_{12}\Phi_{12}(i) + D_{22}\Phi_{11}(i)$ against i is called structural impulse-response function and represents the impact on $Y1$, over time, of a structural shock to $Y2$ at some point in time. The plot of $\sum_{i=0}^{n}D_{12}\Phi_{12}(i) + \sum_{i=0}^{n}D_{22}\Phi_{11}(i)$ against i is called accumulated impulse-response function. While the former represents the impact of a one-time shock on the outcome variable, the latter gives the impact of a permanent shock.

As should be clear from (B11), in order to simulate how an exogenous shock to one variable affects the other variables in the vector y, we need to estimate the matrix D. If we normalize the variance of the structural shocks to 1, so that $E(z_t z_t') = I$, we still need to estimate D using the equation $E(v_t v_t') = DD'$. The main problem is that there are infinite solutions, i.e. an infinite number of matrices D that satisfy this equation. However, the literature has provided several methods to solve this problem and obtain a unique solution, i.e. a unique estimate of D.

The simplest method (also commonly used because it is implemented in standard econometric packages) is the Cholesky decomposition which assumes that D is lower-triangular (in our example, this means assuming that $D_{12} = 0$). The problem with this method is that the shape of the structural impulse-response functions, due to the triangularization of the matrix D, depends on how the variables are ordered in the vector y. So, the shape changes as the order of the variables changes. However, Pesaran and Shin (1998) have provided an extension of the Cholesky method that avoids the ordering problem, meaning that it allows the estimation of structural impulse-response functions which are independent of the ordering of the variables in y. This paper uses the approach proposed by Pesaran and Shin (1998).

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Figure 1. Net energy imports and electricity production

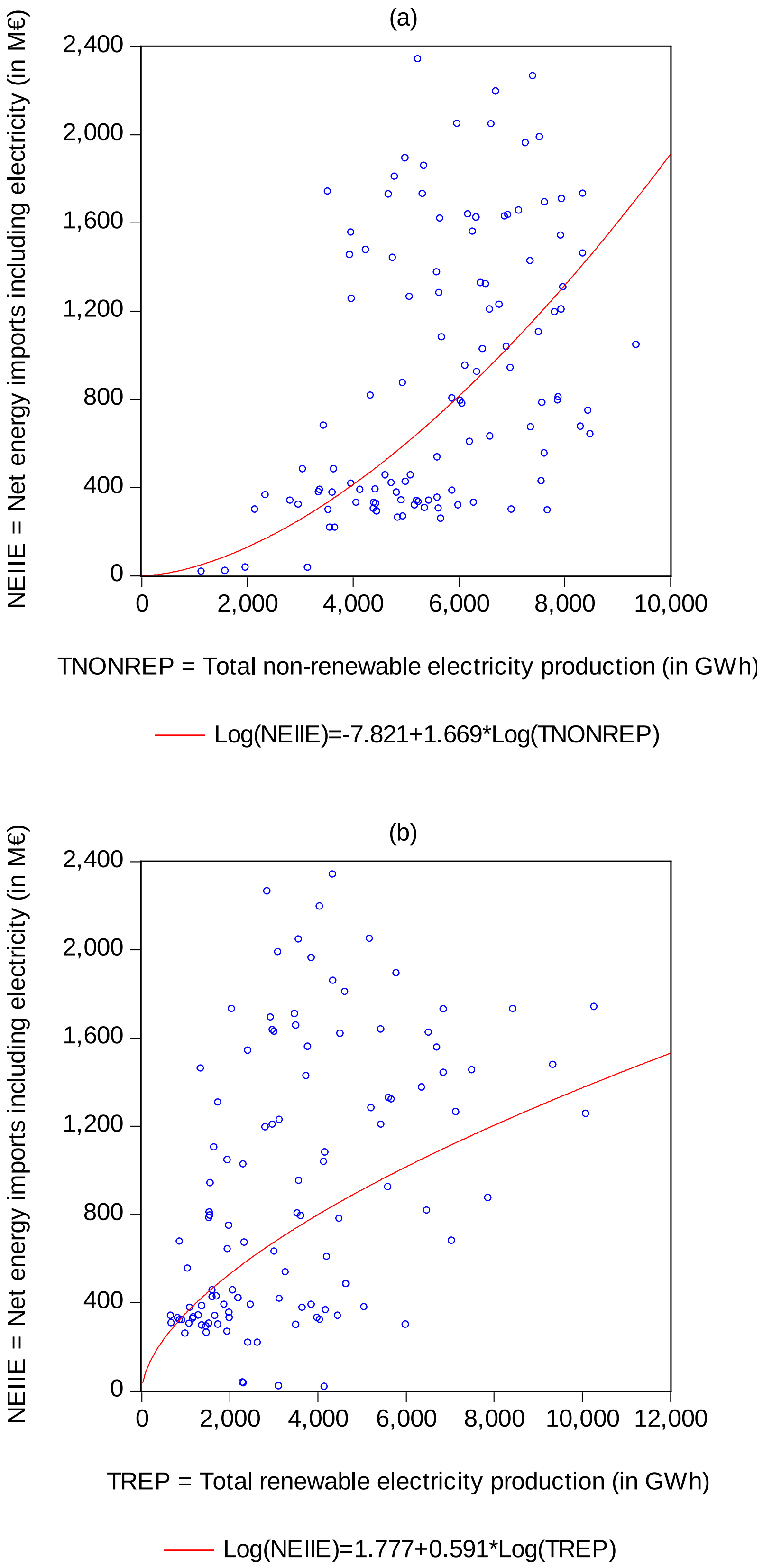
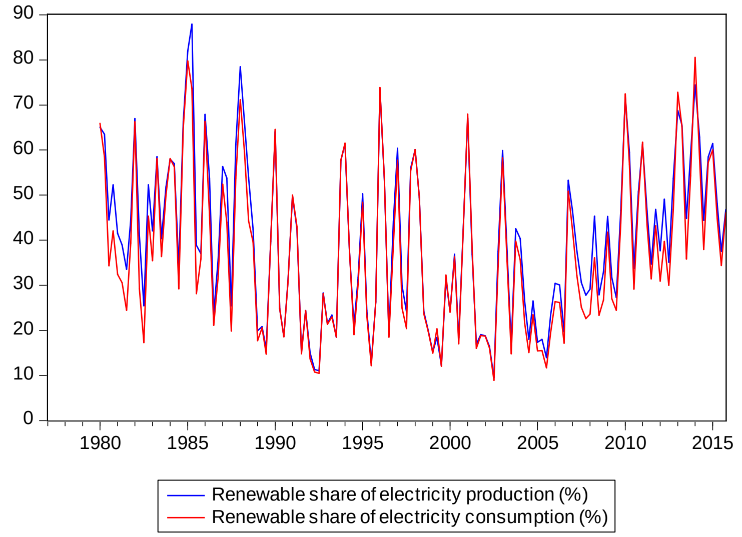


Figure 2. Renewable share of electricity consumption and production



Notes. The vertical axis measures the share of total electricity production (blue line) or consumption (red line) from renewable sources in a given quarter. The maximum over the sample period is 87.9 percent for production and 80.6 percent for consumption. The minimum is 9.5 and 8.8 percent, respectively. For the case of production (blue line), other descriptive statistics are provided in Table 1.

Figure 3. Dataset graphical overview

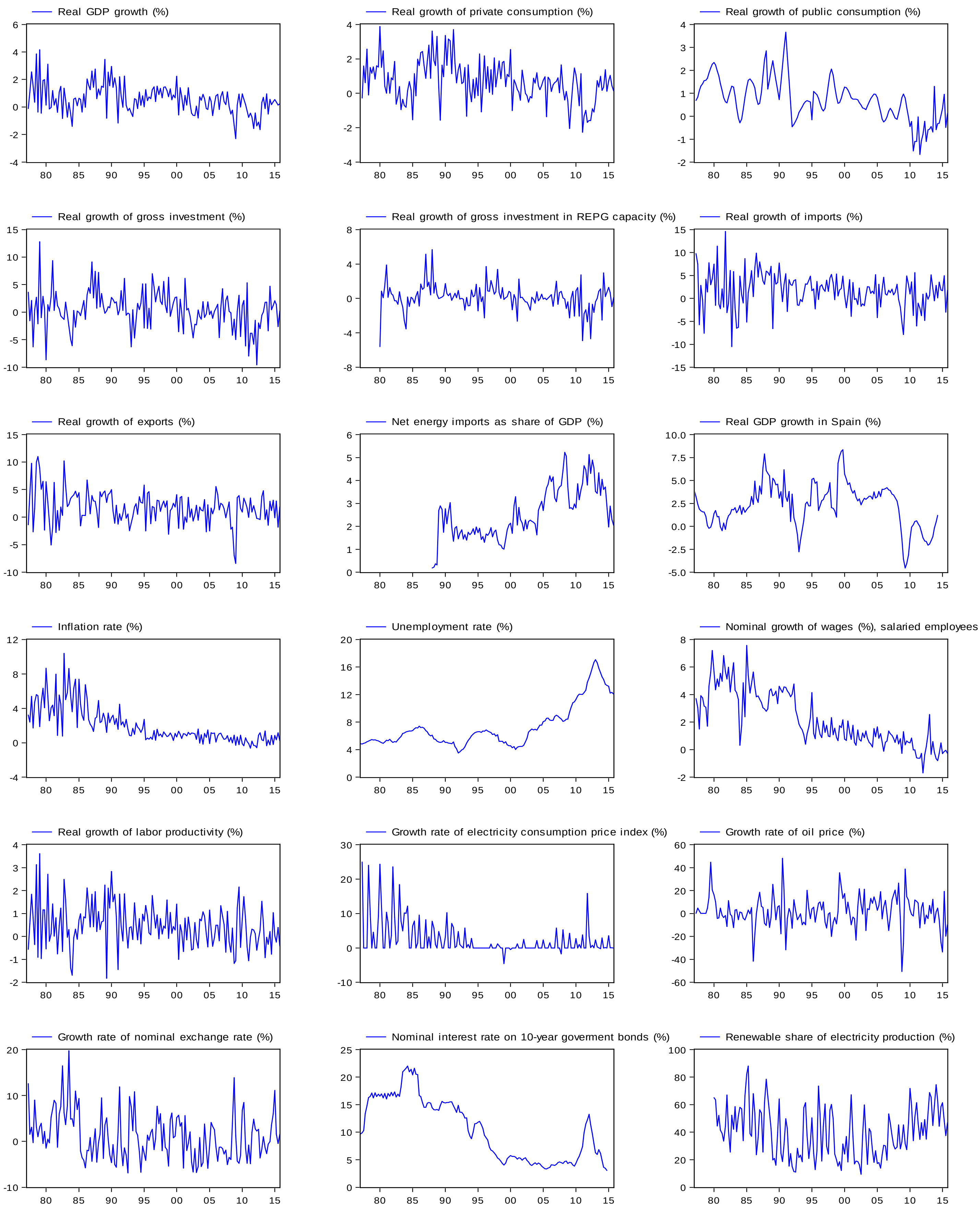


Figure 4. Medium-run effects of a one-time increase in the growth rate of investment in REPG capacity

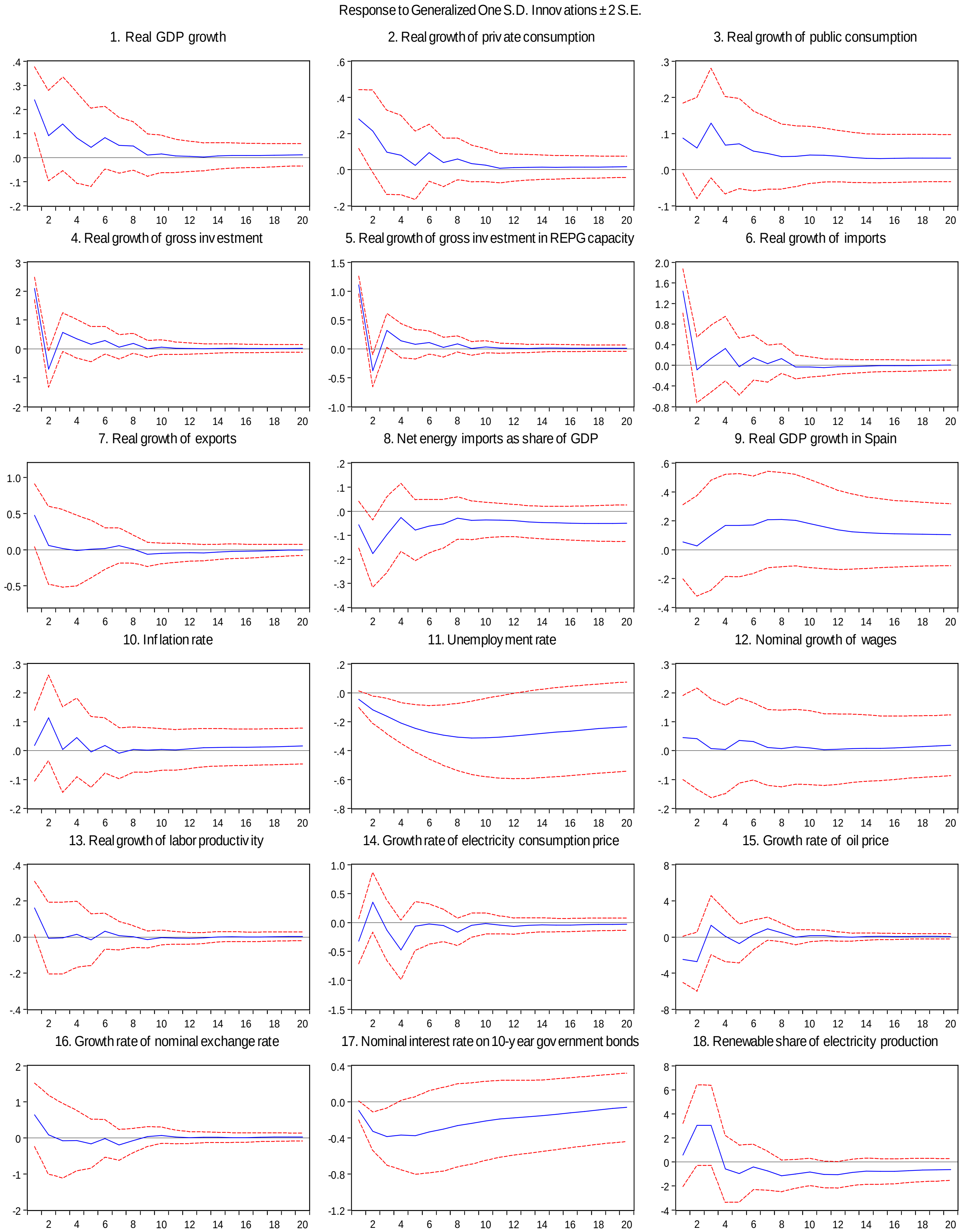


Figure 5. Medium-run effects of a permanent increase in the renewable share of electricity production

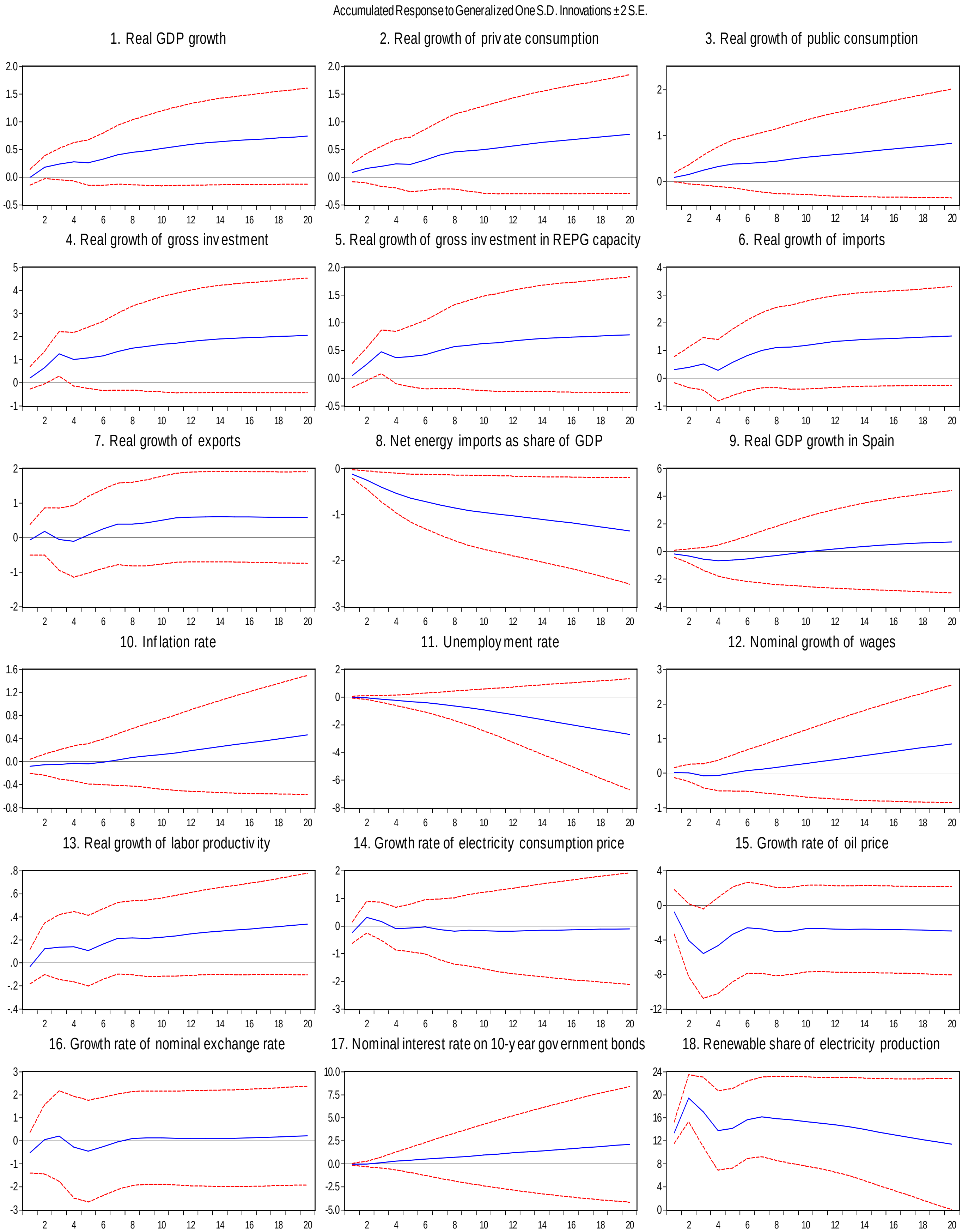


Table 1. Descriptive statistics

	RGG	RGPRC	RGPUC	RGGI	RGGIRC	RGI	RGE	NEISG	RGGS
Mean	0.566	0.672	0.722	0.413	0.116	1.627	1.723	2.558	2.241
Max	4.157	3.880	3.655	12.774	5.663	14.571	10.971	5.219	8.330
Min	-2.300	-2.269	-1.674	-9.588	-5.621	-10.517	-8.403	0.181	-4.540
S.D.	1.059	1.182	0.899	3.411	1.538	3.869	2.945	1.121	2.390
Obs.	155	155	155	155	144	155	155	112	150
Source	BP	BP	BP	BP	BP/REN	BP	BP	INE/BP	INE(E)

	INFR	UNR	NGWSE	RGLP	GRECPI	GROP	GRNER	NIR10GB	RSEP
Mean	1.974	7.301	2.182	0.458	2.495	1.706	1.204	10.462	39.950
Max	10.405	17.067	7.569	3.604	24.985	48.070	19.776	22.030	87.939
Min	-0.637	3.509	-1.701	-1.823	-4.621	-50.526	-6.882	3.050	9.508
S.D.	2.116	3.152	1.978	0.947	5.001	13.798	5.015	5.616	17.830
Obs.	155	156	155	155	155	155	155	152	144
Source	BP	BP	BP	BP	INE	DJC	FRBSL	IMF	REN

Notes. Where not specified, growth rates are quarter-on-quarter. RGG = Real GDP growth; RGPRC = Real growth of private consumption; RGPUC = Real growth of public consumption; RGGI = Real growth of gross investment; RGGIRC = Real growth of gross investment in REPG capacity; RGI = Real growth of imports; RGE = Real growth of exports; NEISG = Net energy imports as share of GDP; RGGS = Real GDP growth in Spain (percent change from the same quarter in the previous year); INFR = Inflation rate (growth rate of the GDP deflator); UNR = Unemployment rate; NGWSE = Nominal growth of wages, salaried employees; RGLP = Real growth of labor productivity; GRECPI = Growth rate of electricity consumption price index; GROP = Growth rate of oil price; GRNER = Growth rate of nominal exchange rate; NIR10YGB = Nominal interest rate on 10-year government bonds; RSEP = Renewable share of electricity production; BP = Banco de Portugal; REN = Redes Energéticas Nacionais; INE = Instituto Nacional de Estatística; INE(E) = Instituto Nacional de Estadística (España); DJC = Dow Jones & Company; FRBSL = Federal Reserve Bank of St. Luis; IMF = International Monetary Fund