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The Role of Renewable Energy in Energy-Related Uncertainty

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Abstract

Renewable energy has been promoted in the Sustainable Development Goal era and may contribute to mitigating energy-related uncertainty that negatively affects economic activities. This paper utilizes local projections for panel data of 28 countries to investigate how the promotion of renewable energy affects the dynamics of energy-related uncertainty. We demonstrate that the use of renewable energy offsets fluctuations in energy-related uncertainty, suggesting the role of renewable energy as an automatic stabilizer. The results incentivize each country to boost its renewable energy use to attain Target 7.2 of the Sustainable Development Goals. Thus, we provide valuable insights for governments to design energy policies and to manage the risk of energy-related uncertainty.

Keywords: Automatic stabilizer, Energy-related uncertainty, Local projections, Renewable energy, Sustainable Development Goals

JEL classification: D80, Q01, Q20, Q43

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1 Introduction

Coping with an increase in energy-related uncertainty is an important issue because such increases are harmful to economic activities.[1] Owing to the rapidly changing situation of energy resources, energy-related uncertainty is volatile and increases unexpectedly. Simultaneously, countries worldwide are currently tackling a global challenge—a major shift in the energy mix—and attempting to boost renewable energy use to attain Target 7.2 of Sustainable Development Goals (SDGs).[2] The transition to renewable energy improves energy self-sufficiency and makes the economy less likely to be affected by uncertain fossil fuel markets; however, the amount of power generated by solar and wind energy varies greatly depending on the season and weather. Thus, while policymakers need to shift to renewable energy considering energy-related uncertainty, it is unclear how promoting renewable energy affects this uncertainty. To clarify these effects, this study examines how the transition to renewable energy affects the behavior of energy-related uncertainty.

[Insert Figure 1]

It is noteworthy that in many countries, the renewable energy share remains low and has not grown substantially, as shown in Figure 1.[3] This figure plots the renewable energy share in total final energy consumption, the formal indicator of Target 7.2, published by the United Nations from 2000 to 2022. One possible reason for this sluggish growth is the free-rider problem in the context of the voluntary provision of public goods.[4] In

[1]Dang *et al.* (2023) recently developed a measure of energy-related uncertainty. They argue that energy-related uncertainty is specifically associated with fluctuations in oil prices, and that an increase in the uncertainty negatively affects economic variables such as output and employment.

[2]Target 7.2 states that "By 2030, increase substantially the share of renewable energy in the global energy mix" (see the United Nations website).

[3]As detailed in the data description below, the renewable energy share in total final energy consumption is reported in the Sustainable Development Report.

[4]Target 7.2 can be viewed as an issue of curbing climate change and a problem of the voluntary pro-

other words, when increasing renewable energy globally, which is currently incurring high operational and installation costs, each country has an incentive to leave the responsibility of Target 7.2 to other countries. As such, it is important to understand what encourages more countries to contribute toward attaining this target. If the use of renewable energy buffers an increase in energy-related uncertainty, countries will benefit from increasing their share of renewable energy, driving them to shift to renewable energy.

In this study, we use panel data for 28 countries to estimate a state-dependent model, in which the states are allowed to change smoothly depending on the renewable energy share in Figure 1. We calculate the impulse responses using local projections that are robust to model misspecification. The empirical method allows us to assess the dynamic responses of the energy-related uncertainty index (EUI) to its own shocks under high and low renewable energy share states.[5]

Our results indicate that renewable energy acts as a buffer against an unanticipated increase in energy-related uncertainty. Specifically, we find that the impact of an EUI shock on the EUI in a high renewable energy share regime is weaker at one to two months after the shock than it is in a low regime. This reveals a new positive aspect of renewable energy use. That is, a high renewable energy share in the total final energy consumption functions as an automatic stabilizer that offsets fluctuations in energy-related uncertainty automatically and immediately. This positive aspect encourages each country to adopt more renewable energy than ever before. Thus far, the extant literature considers renew-

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vision of global public goods (i.e., global share of renewable energy), in which countries are contributors. Standard theoretical analyses that assume noncooperative contributors have reached a consensus that the free-rider problem worsens as the group size increases (e.g., Olson, 1965; Cornes and Sandler, 1985; Mueller, 2003). Translating this consensus into our analysis, the more countries that join the Target 7.2 effort, the bigger the free-rider problem becomes. For a recent survey of global public goods, see Buchholz and Sandler (2021).

[5]As detailed below, the empirical framework has much in common with, for example, Auerbach and Gorodnichenko (2012), Abiad *et al.* (2016), Honda and Miyamoto (2021), and Sheng *et al.* (2022).

able energy from the perspective of environmental protection (e.g., Panwar *et al.*, 2011). Unlike the extant literature, as detailed in Section 2, this study discusses a novel value for renewable energy as an automatic stabilizer against volatile energy-related uncertainty. While Işık *et al.* (2024) advocate a similar role of renewable energy at the global level, this study provides the first country-level evidence that is instrumental in discussions about achieving Target 7.2 of the SDGs.

The remainder of this paper is organized as follows. Section 2 reviews previous works on energy-related uncertainty and renewable energy. We also highlight the importance of examining the role of renewable energy in uncertainty management. Section 3 explains our empirical framework. After providing the data description and summary statistics, we lay out the empirical method. Section 4 presents the results and discussion. Section 5 concludes the paper.

2 Literature review

The present study is at the intersection of two streams of research. The first deals with energy-related uncertainty and the second addresses renewable energy. In this section, after presenting the literature review of these two streams, we review the extant literature that analyzes the relationship between energy-related uncertainty and renewable energy. This review does not include the empirical method, because it is standard and well-established. Instead, some closely related works on the method will be mentioned in the empirical analysis section.

2.1 Energy-related uncertainty

Since the influential works by Bloom (2009) and Baker *et al.* (2016), economic uncertainty has received much attention because of its negative effects on economic activities both at home and abroad. For example, Stockhammar and Österholm (2016) find that an increase in U.S. policy uncertainty affects Swedish GDP growth negatively. Moreover, Bartsch (2019) argues that non-policy market uncertainty destabilizes exchange rates. Thus, this strand of literature indicates that an increase in economic uncertainty of a country has negative effects not only on domestic variables but also on foreign ones.

Another strand of literature investigates how economic uncertainty is created, although the literature has been sparse so far. Duca and Saving (2018) suggest that the economic misery index and media fragmentation have positive effects on economic policy uncertainty in European countries and the United States. Funashima (2022) documents that the Federal Reserve's unconventional monetary policies such as forward guidance are one of the determinative factors of U.S. economic policy uncertainty. Moreover, Funashima (2024) argues that newspaper-based economic policy uncertainty overreacts to a permanent shock because of the nature of the media.

The EUI has only recently been developed by Dang *et al.* (2023), who follow Ahir *et al.*'s (2022) method. They demonstrate that, as in earlier uncertainty indexes, an increase in the EUI has harmful effects on economic variables. Moreover, they show that the EUI is likely to be driven by oil shocks. Zhang and Guo (2024) utilize the EUI to test whether energy-related market uncertainty is predictive of oil price volatility. The EUI has continued to attract significant attention, and its use has proliferated in recent studies (e.g., Işık *et al.*, 2024; Sultanuzzaman *et al.*, 2024).

2.2 Renewable energy

There is a considerable amount of literature on the development of renewable energy. Wang and Zhang (2021) analyze how free trade affects renewable energy development using data for 186 countries from 1990 to 2015. They point out that the effects of free trade on renewable energy development is positive for high and upper-middle income countries, but negative for lower-middle-income countries. Moreover, they report that economic development and technological progress are drivers of renewable energy development in 186 countries.

Wang *et al.* (2022) use panel data for 32 OECD countries from 1997 to 2019 and examine how renewable energy consumption is affected by institutional quality and political risk. They find that institutional quality and GDP per capita can increase renewable energy consumption, whereas the long-run effects of globalization and political risk on renewable energy consumption are negative.

Appiah *et al.* (2023) utilize a panel quantile autoregressive distributed lag approach for the panel data of 21 developing economies from 2000 to 2021 to investigate how renewable energy development is affected by financial development, fiscal policy, and foreign capital. They show that financial development and fiscal policy hamper renewable energy development in the long run. They also find that industrialization and institutional quality are factors determining a declining trend in renewable energy development in the developing economies.

Therefore, previous works have shown what promotes or obstructs the promotion of renewable energy. However, searching for potential roles for renewable energy is still necessary, although until now it has been considered an environmentally preferable energy (e.g., Panwar *et al.*, 2011). This paper uncovers a new role for renewable energy as an automatic stabilizer and argues that from the perspective of the risk management of energy-market uncertainty, increasing renewable energy consumption has more advantages than previously thought.

2.3 The relationship between energy-related uncertainty and renewable energy

As seen above, many previous studies examine both economic uncertainty and renewable energy. However, to the best of our knowledge, economic uncertainty and renewable energy have been treated separately in the literature; thus, little is known about the relationship between energy-related uncertainty and renewable energy.

An important exception is Işık *et al.* (2024), who utilize the autoregressive conditional heteroskedasticity model to demonstrate that renewable energy can mitigate uncertainty in global energy markets. While this paper is closely related to Işık *et al.* (2024), unlike their study, we employ country-level data instead of global-level data. Consequently, we offer evidence that contributes to a deeper understanding of the free-rider problem (see footnote 4).

Another exception is Shafiullah *et al.* (2021) who show that an increase in economic policy uncertainty decreases renewable energy consumption. This paper differs from Shafiullah *et al.* (2021) in that it focuses on the reverse causality, whereas Shafiullah *et al.* (2021) investigate the effects of uncertainty on renewable energy consumption. That is, we explore how the share of renewable energy consumption affects the dynamic behavior of energy-related uncertainty. Moreover, our concern is energy-related uncertainty, whereas Shafiullah *et al.* (2021) deal with economic policy uncertainty.

3 Empirical framework

3.1 Data

We use the EUI developed by Dang *et al.* (2023), which can be retrieved from the Economic Policy Uncertainty website.[6] The renewable energy share in total final energy consumption (SDG Index, sdg7_renewcon) comes from the Sustainable Development Report website.[7] The dataset comprises monthly observations and unbalanced panel data for 28 countries. As the renewable energy share is available from 2000, the sample period is January 2000 to October 2022.

[Insert Figure 2]

Figure 2 shows the EUI with an inverse hyperbolic sine transformation, because the original series includes zeros. As argued in Bellemare and Wichman (2020), this transformation is widely used as it can accommodate zero values and serves as the approximation of natural logarithm transformation. The behavior of the EUI appears to differ from one country to another, although a common trend is observed.

As briefly mentioned earlier, Figure 1 plots our series of the renewable energy share by country. It is apparent from this figure that the renewable energy share and its behavior are completely dissimilar across countries, which would help us assess the role of renewable energy from an analytical perspective. In Brazil, renewable energy accounts for an extremely large proportion because of the large scale of hydroelectric power generation that utilizes abundant river water. Over the past 20 years, Nordic countries such as Sweden and Denmark have made progress in creating low-carbon societies by using power

[6]The EUI is posted at `https://www.policyuncertainty.com/energy_uncertainty.html`.

[7]The SDG Index is available at `https://dashboards.sdgindex.org/explorer`.

generation methods that take advantage of each country's topography; thus, the shares have grown substantially in these countries. By contrast, Russia and Singapore continue to have very low shares of renewable energy over this sample period. The renewable energy share is rising in countries such as Japan, the United Kingdom, and the United States, but there is still room for growth and they need to accelerate further if they are to contribute significantly to achieving Target 7.2 of the Sustainable Development Goals. Chile's renewable energy share tends to decrease rather than increase.

[Insert Table 1]

Summary statistics are given in Table 1. The mean of renewable energy share is 22.47 percent, indicating that as far as our sample is concerned, there is a lot of room to increase renewable energy overall.

3.2 Econometric methodology

We now present our empirical method, using the panel data just described (country and month are denoted by i and t, respectively). We use Jordá's (2005) local projections to examine the response of the EUI to shocks and investigate whether renewable energy share changes the responses. Although our econometric method is similar to that used by Sheng *et al.* (2022), who evaluate the roles of climate risks on the dynamics of economic policy uncertainty at U.S. state-levels, we are interested in different questions.

As a preliminary step to analysis, we need to construct the shocks to the EUI (denoted by $shock_{i,t}$) which will be used in the model estimation. The shocks to the EUI should ideally capture unanticipated disturbances. To derive the intended series, following Sheng *et al.* (2022), we consider shocks to the EUI as components that deviate from its own lags.[8] Specifically, we estimate $shock_{i,t}$ as the residuals in the following regression:

$$\sinh^{-1}(y_{i,t}) = \sum_{j=1}^{p} \phi_j \sinh^{-1}(y_{i,t-j}) + \alpha_i + \varepsilon_{i,t}, \tag{1}$$

where $y_{i,t}$ is the EUI with an inverse hyperbolic sine transformation for the reasons stated above, α_i is country fixed effects, and $\varepsilon_{i,t}$ is the error term. As in Sheng *et al.* (2022), p is set to 12 as a benchmark.

Having described how $shock_{i,t}$ is constructed, we next present the estimation models to address the questions. As our baseline specification, for each horizon h, we consider the estimation model:

$$\sinh^{-1}(y_{i,t+h}) = \beta^h shock_{i,t} + \alpha_i^h + \gamma_t^h + \varepsilon_{i,t}^h, \tag{2}$$

where γ_t is the time fixed effects and the other notations are similar to (1). While acknowledging that there may be control variables that are not available as monthly data for our 28 countries, local projections are robust to misspecification as shown in Jordá (2005). Thus, we use the local projection to compute the impulse responses of the EUI to its own shocks by estimating (2) for each h.

We examine whether the EUI responds differently to its own shocks depending on whether the renewable energy share is high or low. To address this concern, we extend the baseline model to the state-dependent model where the impulse responses are allowed to change depending on the state of the renewable energy share. The state-dependent specification is well-established as in Auerbach and Gorodnichenko (2012), Abiad *et al.* (2016), Honda and Miyamoto (2021), and Sheng *et al.* (2022), among others. Formally,

[8] Sheng *et al.* (2022) estimate the shocks to state-level economic policy uncertainty in the United States.

the state-dependent specification is expressed as

$$\begin{aligned}\sinh^{-1}\left(y_{i,t+h}\right) = \beta_L^h F(z_{i,t}) shock_{i,t} + \beta_H^h \left(1 - F(z_{i,t})\right) shock_{i,t} \\ + \alpha_i^h + \gamma_t^h + \varepsilon_{i,t}^h,\end{aligned} \tag{3}$$

where $z_{i,t}$ is the renewable energy share normalized to have zero mean and unit variance, and $F(z_{i,t})$ is the smooth transition function:

$$F(z_{i,t}) = \frac{\exp\left(-\eta z_{i,t}\right)}{1 + \exp\left(-\eta z_{i,t}\right)}, \tag{4}$$

with $\eta > 0$. It is difficult to divide $z_{i,t}$ into two values (i.e., high or low); therefore, we utilize the smooth transition function instead of a dummy variable. As a benchmark, we set $\eta = 1$ as in Abiad *et al.* (2016) and Honda and Miyamoto (2021). Similar to the estimation of baseline specification, state-dependent specification is also estimated using the local projection method, which is robust to misspecification.

4 Results and discussion

4.1 The shocks to EUI

Figure 3 presents our measure of the shocks to the EUI, which is obtained from the estimation of (1). While the resulting series is a component of the EUI, it is not predictable from the movements of the EUI in the past 12 months. The standard deviation is approximately 0.524, which is not small relative to the standard deviation of the original series (Table 1). The pattern of fluctuations differs depending on the country. Because the estimates of the shocks derive from taking the residuals of the autoregressive model, they reflect all exogenous influences on energy-related keywords in Dang *et al.* (2023).[9]

[Insert Figure 3]

4.2 The responses of EUI to the shocks

Figure 4 shows the impulse responses of the EUI to the shocks assumed to arise when time represented on the horizontal axis is zero. The solid line with circles represents the baseline response in the estimation of (2). The solid line represents the state-dependent response in the estimation of (3), whose 90 percent confidence interval is indicated by the shaded region. The state-dependent response in the left (right) panel shows the case in which the renewable energy share is low (high).

[Insert Figure 4]

The results indicate that the simultaneous responses are the largest in all horizons. Moreover, the simultaneous responses are likely to be almost the same regardless of the states of renewable energy share. However, we can observe an obvious difference in the responses across the states of renewable energy share. In the low renewable energy share state, one to three months after the shock, the response is greater than the baseline response. By contrast, the high-state response was smaller than the baseline response. This remarkable difference suggests that renewable energy increases energy self-sufficiency and reduces the uncertainty caused by exogenous fluctuations in the fossil fuel market.

[Insert Figure 5]

[9] See Dang *et al.* (2023, Table 1) for the keywords that construct the EUI. To name a few, the keywords include climate change, crude oil, energy efficiency, environment, gasoline price, greenhouse gases, natural resource, oil export ban, oil well, pipeline, solar cell, and carbon footprint.

4.3 Robustness

Because these results are based on some tentative settings, it is important to examine the robustness of the findings. First, a key component of our empirical strategy is how the shocks to the EUI are constructed. Therefore, we assess whether the results are sensitive to alternative values of p that we set to 12 as in Sheng *et al.* (2022). Although it seems reasonable to set p to 12 because our data are monthly observations, we also use longer lags to calculate $shock_{i,t}$. Figure 5 plots the results using $shock_{i,t}$ based on the regression with 18 lags. The responses are mirrored in Figure 4 and our findings are robust to alternative shock measures. Second, following previous works such as Auerbach and Gorodnichenko (2012), Abiad *et al.* (2016), and Honda and Miyamoto (2021), we consider alternative values of η. When we set $\eta = 1.5$ as in the literature and recalculate the impulse responses the results are unaffected. Finally, similar responses are confirmed when a lag of the renewable energy share is used.

4.4 Renewable energy as an automatic stabilizer

These results suggest that a high share of renewable energy alleviates the effects of EUI shocks on the EUI at one to two months after the shock. While referring to related literature, we now discuss what our results suggest more specifically.

Our results link to those of Dang *et al.* (2023), although it should be noted that their sample is different from ours; that is, they conduct vector autoregressive analysis for time-series data of the United States in the period from 1996 to 2022. In response to a shock in the EUI, they show that GDP and industrial production continues to decline even one year after the shock, while depressions in the energy sector, employment, and inflation are transient and almost disappear within 9 months after the shock.

Combining our results with those of Dang *et al.* (2023), we can infer the following points. Increasing the share of renewable energy can mitigate the negative impact on many key macroeconomic indicators when an EUI shock occurs. This can serve as incentives for governments to boost their renewable energy use. However, the mitigation effect may be limited, because we only find the effects of the EUI shock on the EUI at one to two months after the shock. As noted earlier, our data and methods differ from theirs, so these inferences should be taken with caution.

In summary, we obtain an important implication that renewable energy can serve as an automatic stabilizer. Although our results indicate that there are slight lags (one to two months) before the mitigating effect appears, they seem smaller than the lags when the energy-related uncertainty is controlled through discretionary fiscal policy. Ramey (2011) points out that after government spending is decided, it takes a long time before it is actually spent. Moreover, the effects of discretionary fiscal policy are uncertain because they depend on the implementation lags (e.g., Christiano*et al.*, 2011; Tsuruga and Wake, 2019). By contrast, once the renewable energy share is increased, the risk of any lag appears to be small in our automatic stabilizer because no action is required by the government and the built-in mitigating effects work automatically. Automatic stabilizers are usually discussed in the context of tax and social insurance system (e.g., Auerbach and Feenberg, 2000; Devereux and Fuest, 2009; Buettner and Fuest, 2010; McKay and Reis, 2016; Paulus and Tasseva, 2020; McKay and Reis, 2021), and our automatic stabilizer could be a novel countercyclical weapon. However, we acknowledge that the theoretical mechanisms through which our automatic stabilizer works should be examined further, which we defer to future research.

5 Conclusion

Renewable energy has been considered clean and is recommended in the SDG era. In fact, boosting renewable energy use is a pressing issue against the background of recent human-related climate change (e.g., Hsiang and Kopp, 2018; Nordhaus, 2019). However, the cost of introducing and promoting renewable energy is not cheap, so far at least, and the transition to renewable energy has not yet been reached.

In the literature, the merit of renewable energy has not been fully investigated. This paper examines the role of renewable energy from the perspective of taming volatile energy-related uncertainty. In addition to simply aiming for a transition to clean energy, it is important for policymakers to consider that, as shown in Dang *et al.* (2023), an increase in energy-related uncertainty has a negative impact on economic activity such as output, employment, and price. Such comprehensive consideration makes formulating desirable energy policies possible.

This study provides new evidence in favor of renewable energy use and underscores the pivotal role of renewable energy in managing energy-related uncertainty. Specifically, we find that fluctuations in uncertainty are moderated in countries with a high share of renewable energy use. This finding suggests the role of renewable energy as an automatic stabilizer, which can guide each country to contribute toward attaining Target 7.2 of the SDGs.

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Table 1: Summary statistics

Variables	Mean	Standard deviation	Min	Max
Energy-related uncertainty	3.55	0.75	0	5.22
Renewable energy share	22.47	22.44	0	95.96

Notes: The sample size is 7,514. An inverse hyperbolic sine transformation is applied to energy-related uncertainty. Renewable energy share is presented as a percentage.

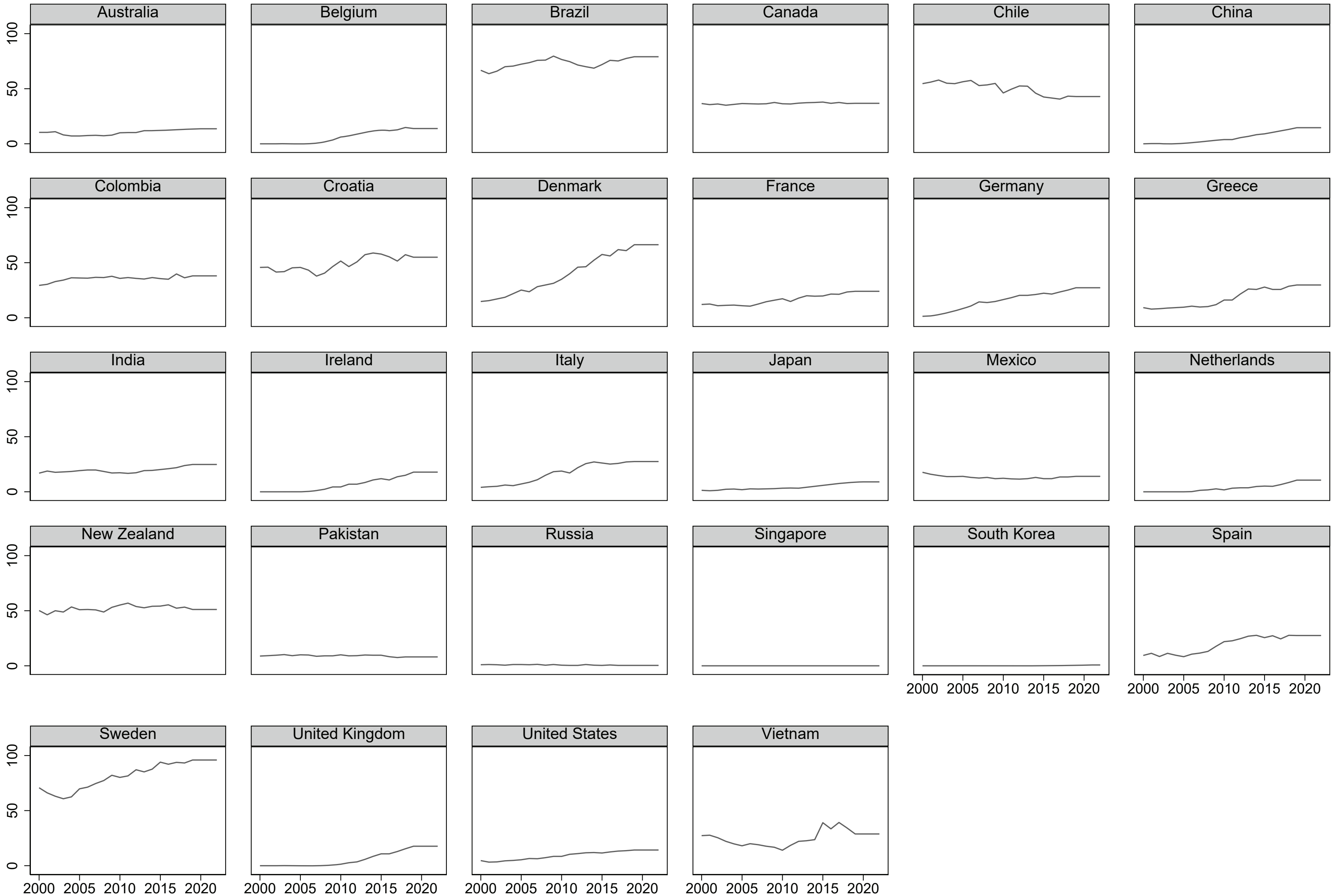

Figure 1: Renewable energy share in total final energy consumption (%)

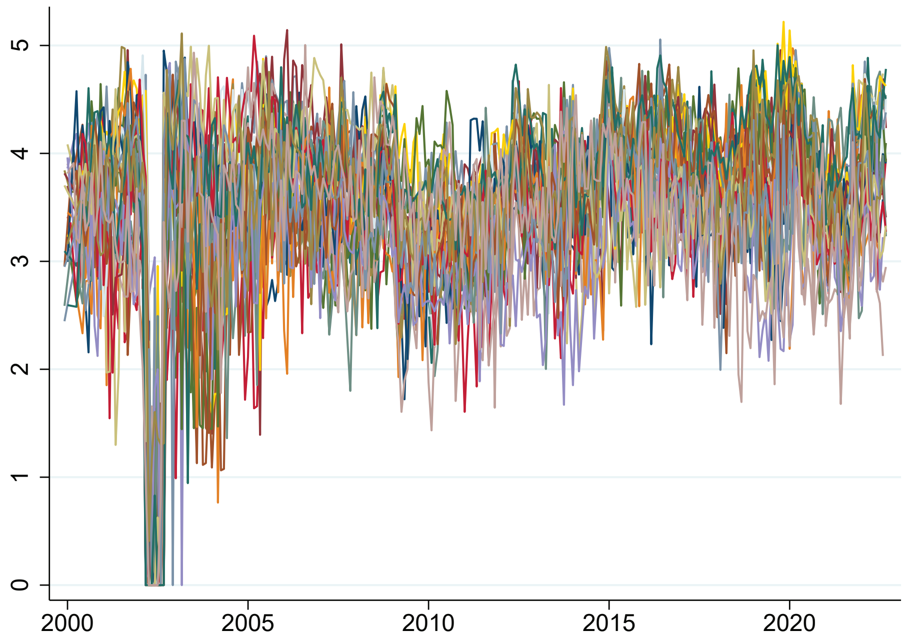

Figure 2: EUI for 28 countries (the inverse hyperbolic sine transformation)

Figure 3: Measure of the shocks to EUI

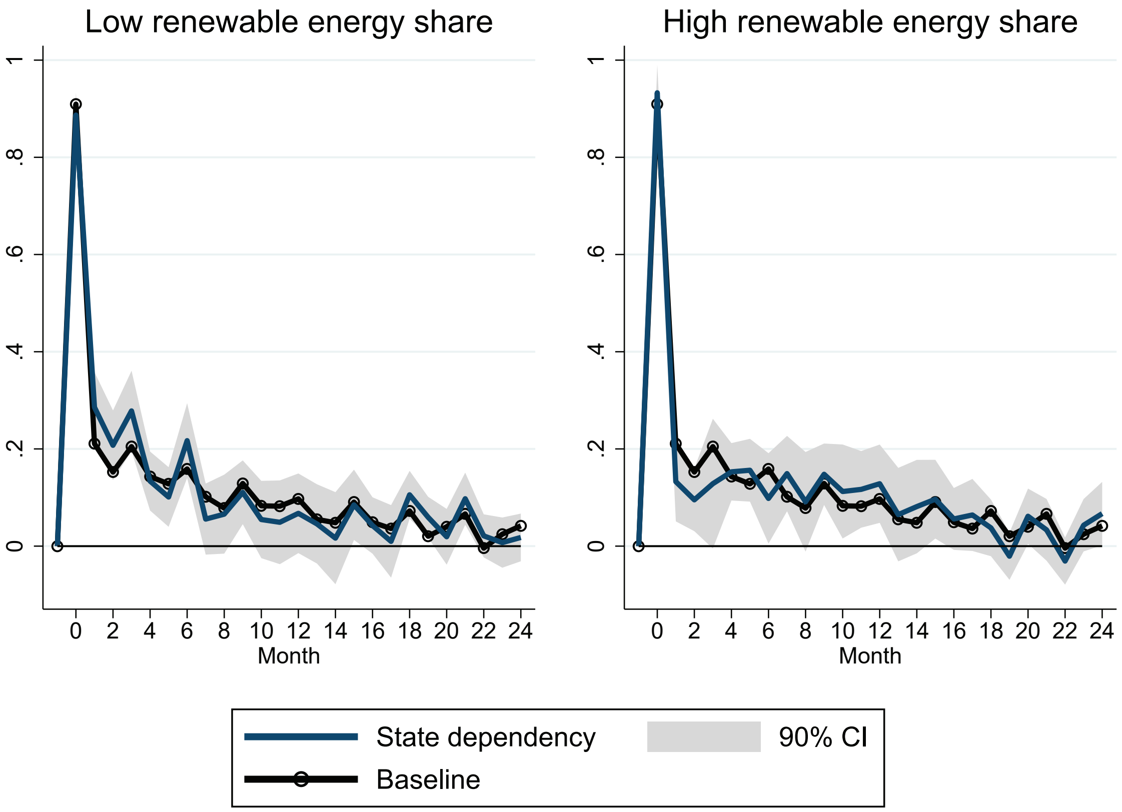

Figure 4: Impulse responses of EUI to its own shocks

Notes: The shock arises when the time is zero. The solid line with circles indicates the baseline response in the estimation of (2). The solid line represents state-dependent responses in the estimation of (3), whose 90 percent confidence interval is indicated by the shaded region.

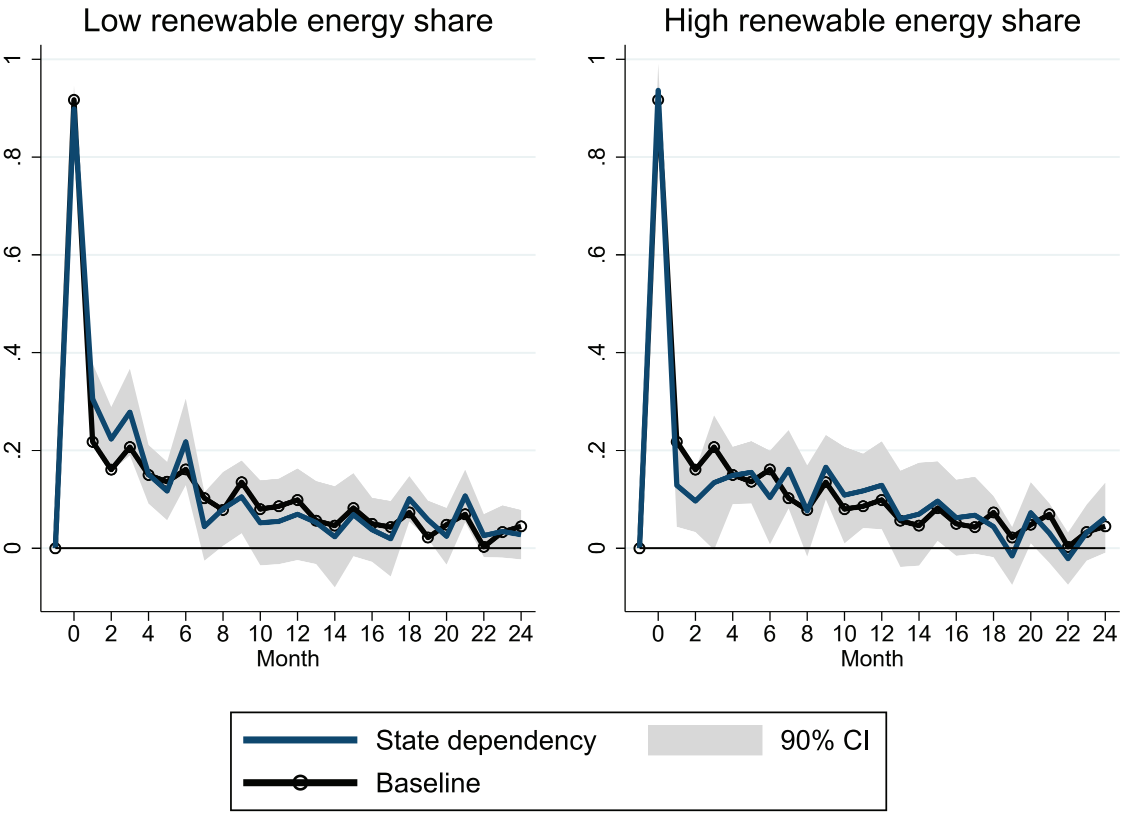

Figure 5: Impulse responses of EUI to its own shocks (a robustness check)

Notes: The shock arises when the time is zero. The solid line with circles indicates the baseline response in the estimation of (2). The solid line represents state-dependent responses in the estimation of (3), whose 90 percent confidence interval is indicated by the shaded region.