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Summary

We investigate whether the degree of energy dependency of countries influences their macroeconomic performance in terms of long-run growth. Specifically, we study whether the impact of energy price changes on economic growth differs depending on a country's degree of energy dependency. There are two novel aspects in this paper. First, all energy commodities are considered, not only oil, and second, our work goes beyond the standard distinction between energy importing and exporting countries. We claim that energy importing and exporting countries are too heterogeneous in terms of net energy imports, energy consumption, and level of development to be clustered and analysed together. Relying on a sample clusterization in groups of countries with a similar degree of energy dependency and using a cross-sectionally augmented panel autoregressive distributed lag (CS-ARDL) approach, we show that countries with a high degree of energy dependency are associated with a negative and significant long-run energy price elasticity of GDP, while countries with a low degree experience the opposite effect, and more balanced countries are less or not significantly affected. Moreover, we contribute to the resource curse paradox showing that the energy price volatility negatively affects the long-run economic growth of countries with a low degree of energy dependency, but it does not hamper the long-run growth of other countries. We argue that the impact of energy price changes differs across countries with a different degree of energy dependency and that a balanced degree of energy dependency is preferable. Therefore, we suggest major energy importers should reduce their degree of energy dependency, while major energy exporters may differentiate their energy production, avoiding to rely only on fossil sources. Renewable sources may be a key driver to improve the management of the degree of energy dependency.

Keywords: Energy Price, Volatility, Energy Security, Economic Growth, Heterogeneous Panel, Institutions, Resource Curse

JEL Classification: C23, C33, O43, Q33, Q43

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Energy Dependency and Long-Run Growth*

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Abstract

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1 Introduction

Energy security is an issue of strategic importance for governments, firms, and households. It is a dynamic and polysemic concept (Chester (2010), Vivoda (2010)), which can be decomposed into seven main issues: energy availability, infrastructure, energy prices[1], societal effects, environment, governance, and energy efficiency (Ang et al. (2015)). Due to its changing and multidisciplinary nature, energy security is studied by several academic branches, such as political science, sociology, engineering, and economics.
However, economists have mainly focused on the economic consequences of energy price and supply shocks, finding that such effects can vary across countries depending on several factors, including, most notably, energy dependency. Indeed, energy dependency is a major concern for all geopolitical players because losses and damages caused by energy price fluctuations and supply shortages can be very serious. Nonetheless, energy dependency is not being treated as a primary issue by governments and it is not much present in the political debate, but in times of rising energy prices or disruptive supply shortages. This situation is probably due to the fact that the solutions to energy dependency issues are typically complex, expensive and take some time to be effective. Only a few countries have remained focused on energy dependency issues since the oil crises the seventies, the USA are among them, regardless of their limited degree of energy dependency with respect to other advanced and emerging countries. On the other hand, European countries are some of the most exposed to energy dependency risks, being poor of fossil sources and relying on a few suppliers, while not having a common and strong international position. However, their energy efficiency and energy intensity are noticeable, unlike the ones of other industrialized countries such as the US, Canada, and Australia. This is probably due to fossil sources abundance or scarcity. Indeed, a reduction of energy consumption is a straightforward strategy to decrease energy dependency, via the augmentation of energy efficiency and the reduction of energy intensity. Other relevant strategies consist in diversifying suppliers and energy mix, and limiting the reliance on major energy exporting countries to reduce their market power. A more recent strategy to curtail energy dependency is the augmentation of renewable energy production. Nevertheless, despite the number of potential strategies, only a few countries have really committed to these policies.
By contrast, this paradigm does not apply to major energy exporters, such as Middle-East countries, that are going through a different path. These countries are facing the energy transition challenge, hoping to maintain their energy exporting role when global economies will no longer be carbon-based.

In this framework, we study the macroeconomic implications on growth of energy price fluctuations in countries with a different degree of energy dependency. The results of the analysis may help policymakers in the design of optimal macroeconomic and energy policies, which will be needed in light of a changing world. Indeed, the commitments of the vast majority of world countries to be carbon-neutral in the next future, the new challenges arising from the technological progress in fossil and renewable industries, from climate change, from the Covid-19 pandemic and from recurring energy price crisis have been triggering and/or boosting dramatic changes in our societies, that in the near future may have some disruptive effects on global energy security and growth.
Our analysis is aimed at underlining the implications of different energy profiles on the macroeconomic growth of countries. We study whether the long-run impact of energy price fluctuations on economic growth is uniform in countries with a different degree of energy dependency.
There are two novel aspects with respect to existing macroeconomic literature. The first one is that all energy primary sources are considered in the analysis, not only oil. The main feature of this tentative is removing the asymmetries due to diverse energy commodity imports. For example, Australia is a net oil importer but a non-oil energy exporter, and the UK is a net oil exporter but a non-oil energy importer.
The second novelty is that this work goes beyond the standard distinction between energy importing and exporting countries, since we divide countries using quantiles of energy dependency. We have decided to adopt a more granular classification because countries composing the energy importer and energy exporter clusters are heterogeneous in terms of net energy imports, energy consumption, and in terms of level of development. For example, both Italy and the US are net energy importers, but Italy imports 80% of its total primary energy consumption while the US imports just about 10%. This

[1] The main features of energy price are: energy price level, energy price volatility and the degree of competition of energy markets (Ang et al. (2015)).

classification should allow us to show whether energy price changes have different impacts on long-run growth rates depending on the degree of energy dependency of the considered countries.
In particular, this work estimates the long-run effect of energy price changes and energy price volatility changes on GDP growth, using a cross-sectionally augmented panel autoregressive distributed lag (CS-ARDL) approach that relies on a sample clusterization in groups of countries with a similar degree of energy dependency over time. We produce our analysis using a dataset composed by 48 countries and annual frequency data, covering the vast majority of global GDP in our analysis.

The rest of this work is organized as follows. In Section 2, we define the related literature this work is based on. In Section 3, we introduce the dataset and the division of countries in clusters, using the degree of energy dependency. In Section 4, we present the main model. Finally, Section 5 offers some concluding remarks.

2 Related Literature

This work is based on three streams of literature. The first one investigates the concept of energy security, which is a polysemic and elusive concept, and its main literature references are Kruyt et al. (2009), Chester (2010), Vivoda (2010) and Ang et al. (2015). In these papers, scholars define and analyse the concept of energy security, using various indexes and approaches. Due to its dynamic and complex nature, there is no broad consensus on its precise definition, therefore, a multitude of indicators is used to study it. IEA defines energy security as "the uninterrupted availability of energy sources at an affordable price. Energy security has many aspects: long-term energy security mainly deals with timely investments to supply energy in line with economic developments and environmental needs. On the other hand, short-term energy security focuses on the ability of the energy system to react promptly to sudden changes in the supply-demand balance. Lack of energy security is thus linked to the negative economic and social impacts of either physical unavailability of energy, or prices that are not competitive or are overly volatile." (IEA (2014)). Moreover, IEA evaluates energy security in terms of oil, gas, and electricity security and in terms of weather, climate, and digital resilience.
The index of energy dependency is one of the most used to investigate energy security, as in Pode (2010), Bortolamedi (2015), Bompard et al. (2017), Radovanović et al. (2018), Matsumoto et al. (2018), Trotta (2019). Besides, Radovanović et al. (2017), Filipović et al. (2018), Bluszcz (2017) focus on the energy dependency situation of European countries, which are among the most energy dependent.
We use the World Bank energy dependency index to cluster countries in homogeneous groups and evaluate whether the macroeconomic consequences of energy price fluctuations on stability and growth differ across the clusters.

This work is based on a second stream of literature concerning the methodologies used in our analysis, and it contributes to a third stream of literature investigating the resource curse paradox. Our analysis is based on the stream of literature that studies the macroeconomic consequences of oil price shocks, focusing on cross-country differences over time. This stream is inserted in a much broader branch of literature which concerns the estimation of the macroeconomic effects of oil shocks in advanced countries. Typically, they estimate reduced-form models arising from economic theory. Kilian (2008) is a must-read literature review of economic consequences of energy shocks, covering micro and macro approaches, demand and supply side point of views, various sources of energy shocks. Moreover, it concerns several energy commodities, but it does not consider cross-country variations. Unfortunately, there are not many papers quantifying the economic effects of energy price and supply shocks across different countries. A nice example is Peersman and Van Robays (2012) which uses a Bayesian structural vector autoregressive model (SVAR) with sign restrictions to identify the different responses to oil price and supply shocks of some advanced countries with a diverse profile of energy dependency, i.e. G7 countries plus Switzerland, Norway, and Spain. They find that the consequences of a rise in oil price caused by rising aggregate demand or oil-specific demand are the same across the considered countries. Nevertheless, these consequences are distinct for energy importing and exporting countries when considering a positive oil supply shock. Moreover, they find that countries improving considerably their energy dependency profile are less damaged from oil supply shocks and oil-specific demand shocks. Other examples are Cashin et al. (2014), Mohaddes and Pesaran (2016), Mohaddes and Pesaran

(2017), Mohaddes and Raissi (2019) which exploit global vector autoregressive models (GVAR). These works estimate country-specific impulse response functions obtained by embedding an oil price equation in a dynamic multi-country model. Although being quite innovative, GVAR models do not fully capture the differences in the degree of energy dependency, dividing countries in net oil importers and exporters, without considering other energy commodities.

The third stream of literature investigates the resource curse paradox, assessing that the abundance of oil, or other non-renewable resources, have an unconditional negative long-run effect on GDP growth (Sachs and Warner (1995)). However, recent works, relying on more advanced techniques, show that the problem is not oil or resource abundance *per se*, but its price volatility (De V. Cavalcanti et al. (2011), De V. Cavalcanti et al. (2015), Mohaddes and Pesaran (2016), Jarrett et al. (2019) and Van Eyden et al. (2019)). All these works find empirical support for a negative effect of oil price volatility on growth while estimating a positive effect of a rising oil price. Among them, some analyse the role of institutions suggesting that increasing the quality of institutions, in particular financial institutions (such as sovereign funds), can offset the negative effect on economic growth.

3 Data and Empirical Approach

Our analysis enriches the literature studying how energy price changes influence long-run economic growth taking into account for several confounding variables, with annual frequency.
Table 1 shows the main variables used in this work, covering both advanced and emerging countries, and energy exporting and importing countries, while Table 2 shows the main characteristics of the variables.

Table 1: Dataset

Main Variables	Data Source
Real GDP in PPP in 2011 US\$, $Y_{i,t}$	Penn World Tables 9.0
Population in millions, $Pop_{i,t}$	Penn World Tables 9.0
Degree of Energy Dependency, $ED_{i,t}$	World Bank
Energy Price Index, Pe_t	World Bank
Energy Price Index Volatility, Vol_t	Author's Calculation
Institutional Quality, $Inst_{i,t}$	Fraser Institute
Political Quality, $Pol_{i,t}$	Polity IV Project

Table 2: Overall, Between and Within Variation of the Main Variables

Variable	Obs	Mean	Overall Variation	Between Variation	Within Variation
$Y_{i,t}$	2112	12.68242	1.535682	1.480016	0.4609654
$\Delta y_{i,t}$	2064	0.0331254	0.0480651	0.0147091	0.4609654
$ED_{i,t}$	2112	-125.7954	832.8376	438.9374	710.5469
Pe_t	2112	3.672099	0.6123876	0	0.6123876
ΔPe_t	2064	0.0531927	0.2570177	0	0.2570177
Vol_t	2064	0.1705926	0.1630029	0	0.1630029
$Inst_{i,t}$	2112	5.826688	2.227157	1.750744	1.399128
$\Delta Inst_{i,t}$	2064	0.0761624	0.2772663	0.0521334	0.2724225
$Pol_{i,t}$	1911	4.039246	7.85197	6.971444	3.746498
$\Delta Pol_{i,t}$	1864	0.1319742	1.316222	0.1761946	1.304565

The degree of energy dependency is the main variable of the dataset, it is proxied by the World Bank energy dependency index, $ED_{i,t}$, and it is used to divide countries into five groups.

$$ED_{i,t} = \left(\frac{\text{Net Energy Imports}_{i,t}}{\text{Total Primary Energy Consumption}_{i,t}} \right) \%$$

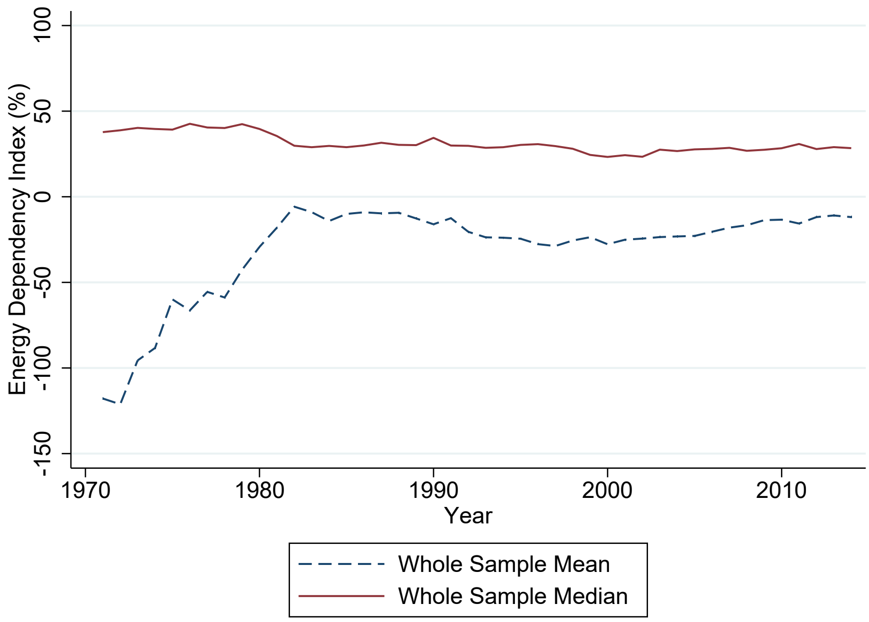
where i represents the country and t is time. The index varies from 100% to $-\infty$, where positive values refer to net energy importing countries, and negative values refer to net energy exporting countries. Net energy imports are estimated as energy use less production, both measured in oil equivalents, and energy use refers to use of primary energy before transformation, which is equal to indigenous production plus imports and stock changes[2]. The Im-Pesaran-Shin unit root test rejects the null hypothesis of homogeneous non-stationarity of this variable (Table 3), and Figure 1 graphically confirms the substantial stability of its mean and median over time. Moreover, the cross-section dependence (CD) test (Pesaran et al. (2004), Pesaran (2015)) does not reject the null hypothesis of cross-section independence (Table 5).

We use the Energy Dependency Index to cluster countries in homogeneous groups because it is a synthetic indicator embedding information on two relevant energy-related features, such as the energy consumption and the net energy import of countries, while following their evolution over time.

As in Table 2, this panel variable has a relevant between and within variation. That is the reason why we suggest countries should be clustered and investigated in accordance to their degree of energy dependency.

Moreover, it is suitable for the clusterization because it is stable over time, as suggested by the panel unit root tests (Table 3). Section 3.1 explains how we use this variable to cluster countries in five groups.

Figure 1: Mean and Median of the Energy Dependency Index



Notes: Saudi Arabia and Oman have been excluded for graphical reasons.

The energy price index is obtained from the Pink Sheet of World Bank Commodity Price Data[3]. It is calculated as a weighted average of coal (4.7), natural gas (10.8), and crude oil (84.6) real prices, which, in turn, are weighted averages of several coal, natural gas, and crude oil prices. For example, the crude oil price used to calculate the energy price index is based on WTI, Brent, and Dubai oil prices. The energy price index varies only through the time dimension since it is a global index for energy commodity

[2] World Bank definition of the Energy Dependency Index.

[3] The quarterly version of this series is an author's calculation based on the monthly version of the energy price index.

prices (Figure 2). The Augmented Dickey-Fuller test does not reject the null hypothesis of presence of unit root in the natural logarithm of the energy price index, namely Pe_t, while it rejects the null hypothesis for the first difference of its natural logarithm, namely ΔPe_t (Table 4).
We have calculated the energy price realized volatility index following the procedure in Jarrett et al. (2019) (Figure 3). This index of realized volatility is not event-based, but it is the standard deviation of the year-on-year growth rate of monthly energy price, from 1971m1 to 2014m12.
The real GDP series we use is in chained-PPP in 2011 US$, it covers 48 countries from 1971 to 2014 with no missing observations and it is obtained from the Penn World Tables 9.0 (Feenstra et al. (2015)). A per capita version of that series is calculated using the population variable, which is present in the same dataset. The Augmented Dickey-Fuller test rejects the null hypothesis of homogeneous non-stationarity of the real GDP series (Table 4).

Table 3: Panel Unit Root Tests, Energy Dependency Index, 1971-2014

Method	Form	Statistic value	p-value
IPS	lag(AIC)	-1.7700	0.0384
IPS	lag(BIC)	-1.2960	0.0975
IPS	lag(HQIC)	-1.5196	0.0643
F-PP	no lags	4.0603	0.0000
F-PP	1 lag	4.6969	0.0000
F-DF	no lags	4.0603	0.0000
F-DF	1 lag	11.0939	0.0000
IPS	demeaned, lag(AIC)	-38.0806	0.0000
IPS	demeaned, lag(BIC)	-38.0806	0.0000
IPS	demeaned, lag(HQIC)	-38.0806	0.0000
F-PP	demeaned, no lags	63.0860	0.0000
F-PP	demeaned, 1 lag	51.8892	0.0000
F-DF	demeaned, no lags	63.0860	0.0000
F-DF	demeaned, 1 lag	124.1416	0.0000

Notes: IPS is the Im-Pesaran-Shin panel unit root test, F-PP is the Fisher-Phillips-Perron unit root test, and F-DF is the Fisher-ADF unit root test. The null hypothesis of the IPS test is that all panels contain unit roots, while the alternative is that some panels are stationary. The null hypothesis of the F-PP and F-DF tests is that all panels contain unit roots, while the alternative is that at least one panel is stationary.

Table 4: Unit Root Tests, 1971-2014

Variable	ADF	KPSS	Lag selection criteria
Pe_t	-2.065	0.201**	AIC / Newey–West Bandwidth
ΔPe_t	-6.507***	0.136*	AIC / Newey–West Bandwidth
Vol_t	-5.112***	0.0699	AIC / Newey–West Bandwidth

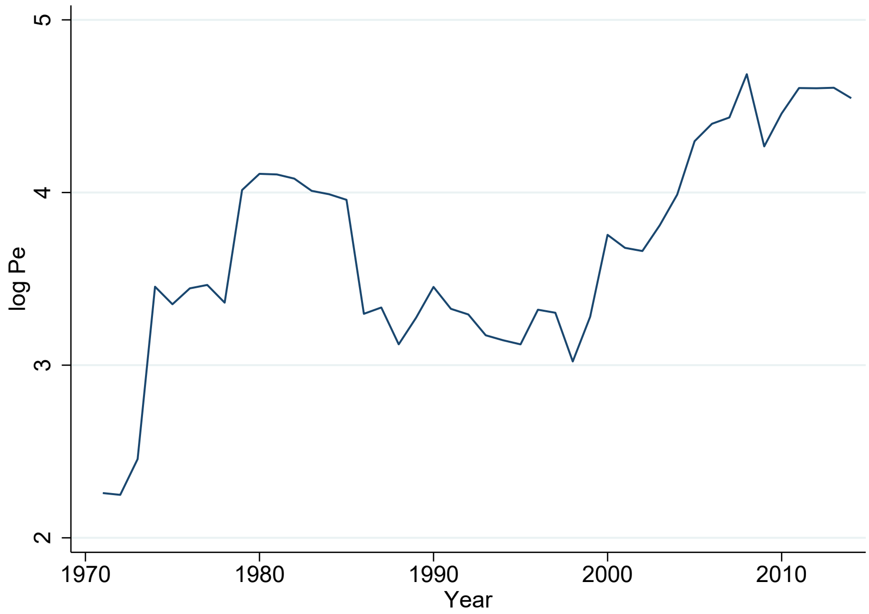
Notes: The ADF is the Augmented Dickey-Fuller Test and its lag selection criteria is based on AIC. The KPSS is the Kwiatkowski-Phillips-Schmidt-Shin Test and its lag selection criteria is the Newey–West Bandwidth.The null hypothesis for the ADF test is the presence of a unit root, while the null hyphothesis of the KPSS test is that the variable is stationary. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 5: Cross-Sectional Dependence Test, 1971-2014

Variable	Statistic value	p-value
$\Delta y_{i,t}$	41.37	0.0000
$ED_{i,t}$	1.87	0.0000
$\Delta Inst_{i,t}$	178.36	0.0000
$\Delta Pol_{i,t}$	31.71	0.0000

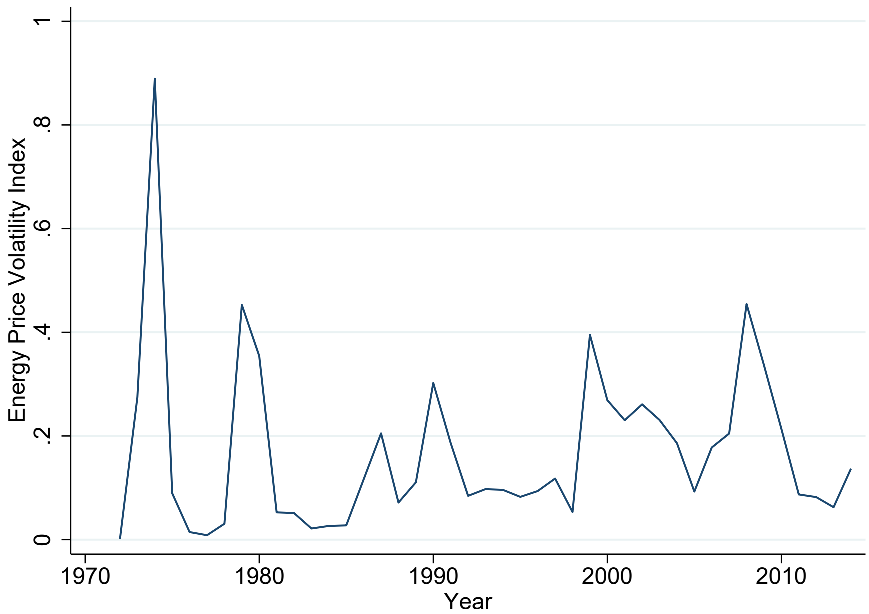
Notes: The null hypothesis for the Cross-Sectional Dependence Test (Pesaran et al. (2004), Pesaran (2015)) is the cross-section independence, while the alternative hypothesis is cross-section dependence.

Figure 2: The natural logarithm of the Energy Price Index



Source: World Bank.

Figure 3: The Energy Price Index Realized Volatility



Notes: Author's own calculations based on World Bank data.

This part of the analysis is extended using institutional quality and political stability as confounding variables. Both series cover the same countries and the same time span of the above-mentioned Penn World GDP series, with no missing observations.
The institutional quality variable is obtained as the average of three of the five sub-indicators composing the Fraser Economic Freedom Index and it varies from 0 to 10. The five sub-indicators are size of government, legal system & property rights, sound money, freedom to trade internationally, regulation. We decided to use only the following sub-indicators: legal system & property rights, freedom to trade internationally, and regulation. It is used to capture the huge heterogeneity in the dataset, due to the differences in the level of development. The Im-Pesaran-Shin unit root test does not reject the null hypothesis of homogeneous non-stationarity for the Institutional Quality variable[4], and the CD test (Pesaran et al. (2004), Pesaran (2015)) rejects the null hypothesis of cross-section independence (Table 5).
The political quality variable captures the regime political authority of countries and it spans from -10 to $+10$, where the two boundaries correspond respectively to complete autocracy and full democracy. This variable is obtained from Polity IV Project (Marshall et al. (2016)) dataset. The Im-Pesaran-Shin unit root test rejects the null hypothesis of homogeneous non-stationarity of the variable[4], and the CD test (Pesaran et al. (2004), Pesaran (2015)) does not reject the null hypothesis of cross-section independence (Table 5).

Table 6: Pairwise Correlation

	$\Delta y_{i,t}$	$\Delta Pe_{i,t}$	$Vol_{i,t}$	$Inst_{i,t}$	$Pol_{i,t}$
$\Delta y_{i,t}$	1				
$\Delta Pe_{i,t}$	0.1140	1			
$Vol_{i,t}$	-0.0129	0.6451	1		
$Inst_{i,t}$	0.0186	-0.0623	-0.0057	1	
$Pol_{i,t}$	0.0509	-0.0040	0.0216	0.3803	1

3.1 Sample Clusterization

Most of the literature divides countries into oil exporting and importing countries, regardless of their advanced or emerging nature and of their net oil import and consumption over time. Moreover, we argue that these differences are even bigger when considering all energy commodities, not only crude oil. Indeed, Table 1 in Peersman and Van Robays (2012) underlines the huge differences in net energy imports and energy intensity in a set of advanced energy importing and exporting countries from 1986 to 2008, while Table 7 shows the differences in terms of energy consumption per capita of the countries we consider in our analysis.
For example, Italy and the US belong to the net energy importing countries but they experience very relevant differences in terms of energy consumption per capita (respectively 113 and 319 exajoule per capita) as in Table 7, energy intensity (respectively 93 and 172 tonnes of oil equivalent per US million dollars in weighted PPP) and net total energy imports (respectively 101 and 57 tonnes of oil equivalent per US million dollars in weighted PPP) as shown in Table 1 in Peersman and Van Robays (2012). The same pattern appears among net energy exporting countries since Canada, Australia, Norway and Middle-East countries have a diverse profile regarding the three above-mentioned energy features.

[4]The test has been performed four times: using Akaike information criterion and no trend, using Akaike information criterion and a linear trend, using Bayesian information criterion and no trend, using three lags.

Table 7: Energy Consumption per capita

Energy exporting countries	Energy consumption per capita, 1965-2019 average	Energy importing countries	Energy consumption per capita, 1965-2019 average
ARE	459	AUT	153
ARG	65	BEL	225
AUS	221	BGR	110
BHR		BRA	39
CAN	381	CHE	162
DZA	35	CHL	55
EGY	25	CHN	38
IDN	15	DEU	178
KWT	367	DNK	155
MEX	51	ESP	102
NGA		FIN	209
NOR	352	FRA	160
OMN	142	GBR	154
QAT	698	GRC	96
SAU	230	HUN	99
ZAF	92	IND	11
		IRL	127
		ISL	367
		ISR	102
		ITA	113
		JPN	144
		KOR	119
		LUX	369
		NLD	217
		POL	116
		PRT	72
		ROU	86
		SEN	
		SWE	249
		TUR	42
		USA	319

Notes: Author's calculation using annual BP data. The averages for the period 1965-2019 of energy consumption per capita are in exajoule.

To deal with these sources of heterogeneity, we split the countries into more than two groups, using their energy dependency index, which concerns both net energy imports and energy consumption. Thus, we build five clusters, as in Table 8, to separate countries with a low degree of energy dependency from countries with a high degree or with a more balanced profile of energy dependency. This allows us to perform our analysis on homogeneous groups in order to disentangle the specific economic features of each cluster of countries and to check whether these features change among clusters.

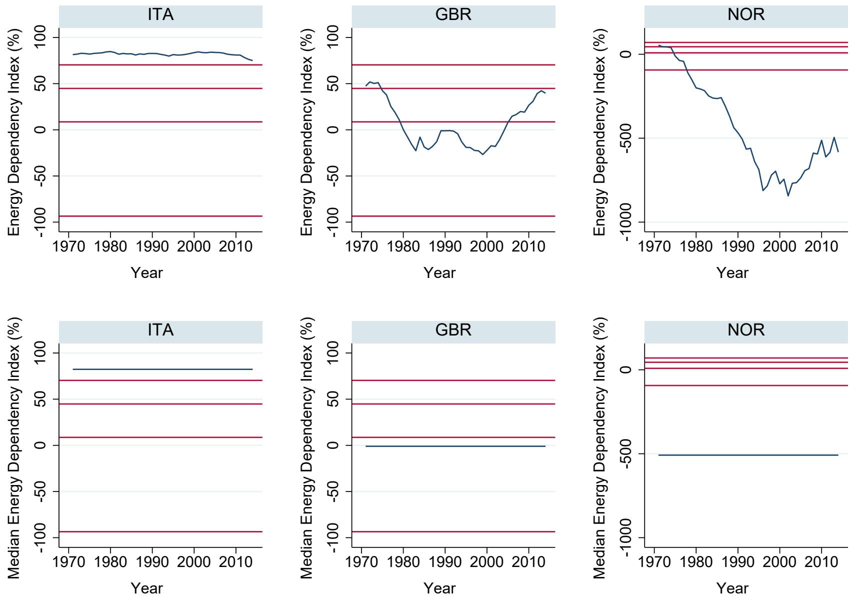
Therefore, the sample is divided into five clusters based on the quintiles of energy dependency, and countries are sorted using the median value of their energy dependency index.

1. Very low degree of energy dependency countries (i.e. ED1)
2. Low degree of energy dependency countries (i.e. ED2)
3. Balanced degree of energy dependency countries (i.e. ED3)
4. High degree of energy dependency countries (i.e. ED4)
5. Very high degree of energy dependency countries (i.e. ED5)

An example of this clusterization methodology is graphically represented in Figure 4, while Table 8 shows the countries composing the five clusters and Table 9 presents the descriptive statistics of the aggregate energy dependency index associated to each group of countries. The individual energy dependency index of each country is shown in Appendix B (Figures B1, B2, B3, B4, and B5).
Using this clusterization method, we build five groups that are balanced in terms of number of countries and observations (Table 8 and Table 9). Moreover, this methodology allows us to represent each country over time and to compare the empirical results among clusters, because countries do not change cluster over time. We can rely on this clusterization method for the above mentioned reasons and because the

energy dependency index is a panel stationary variable, as shown in Table 3, with only a few countries having a non-stationary energy dependency index (typically MENAs and BRIICS)[5]. Consequently, our analyses are reliable over time.

Figure 4: Three examples of the clusterization methodology



Notes: In the first row, the Energy Dependency Index of Italy, Great Britain, and Norway. In the second row, the median of the Energy Dependency Index of the three countries. The red lines are the thresholds defining the five clusters of countries based on the Energy Dependency Index.

Table 8: Clusters of Countries

Clusters	ED1	ED2	ED3	ED4	ED5
Countries	ARE	ARG	BRA	AUT	BEL
	BHR	AUS	DNK	BGR	ESP
	DZA	CAN	IND	CHE	IRL
	KWT	CHN	ISL	CHL	ISR
	NGA	EGY	NLD	DEU	ITA
	NOR	GBR	NZL	FIN	JPN
	OMN	IDN	ROU	FRA	KOR
	QAT	MEX	SEN	GRC	LUX
	SAU	POL	SWE	HUN	PRT
		ZAF	USA	TUR	
No Countries	9	10	10	10	9

Notes: countries do not change cluster over time. Country codes are defined following ISO 3166-1 alpha-3 classification.

An alternative clusterization method to divide countries into clusters could use the first year of the energy dependency index of each country as reference. However, we think this is a sub-optimal method because it may bias the analysis, not taking into account for the relevant transformation in the degree of energy dependency of some countries in the first years of our sample. Indeed, even if the energy dependency index is a very stable variable (Table 3), some countries have non-stationary indexes due

[5]Besides, the non-stationarity of the energy dependency index of MENA countries is not a problem because they are concentrated in the first quintile and their energy dependency indexes are far from reaching the lower bound of the ED2 cluster. Therefore, their non-stationary energy dependency index does not interact with the rule used to divide countries in clusters.

Table 9: Descriptive Statistics of the Energy Dependency Index of each Cluster

	Obs.	Mean	Median	Std. Dev.	Skewness	Kurtosis
ED1	396	-808.7732	-375.6448	1766.51	-6.472091	53.6529
ED2	440	-32.13322	-21.51809	43.42577	-.895235	3.434006
ED3	440	25.67975	23.95699	23.3107	.1595211	5.603342
ED4	440	57.21313	57.49670	11.17165	-.136215	2.411545
ED5	396	81.46474	81.73589	12.91109	-2.513427	17.80289
Whole Sample	2112	-125.7954	26.40433	832.8376	-13.71254	244.1463

Notes: Descriptive statistics are calculated across countries of the same cluster and over time.

to the transformation in the energy policies they have employed to face the oil crises in the 70's. This abrupt change in the energy dependency index involves only a few countries, typically countries with a very low degree of energy dependency. For example, Norway was a net energy importer in 1971, but in a few years its energy dependency profile was completely changed, and nowadays it is one of the major global energy exporting countries.

4 Estimation of Long-Run Effects

4.1 Methodology

To estimate the long-run effect of energy price changes on economic growth, we exploit a cross-sectionally augmented panel autoregressive distributed lag (CS-ARDL) approach, relying on a sample clusterization in groups of countries with a similar degree of energy dependency over time. This panel ARDL approach fits for long-run analysis and has some appealing properties, clearly presented by Pesaran in a series of papers (Pesaran and Smith (1995), Pesaran (1997) and Pesaran and Shin (1998)). These papers show that this approach is robust to the omitted variable bias, that it produces consistent estimates whether the I(0) or I(1) nature of the considered variables, and that it allows for feedback effects among variables.

Furthermore, this approach returns consistent estimates if a sufficient number of lags is used (Chudik et al. (2016)). After considering several lag orders, we decide to rely on 3 lags for all variables because we need to include enough dynamics, since we are focusing on long-run effects, and because we want to avoid any data mining critique due to the use of a diverse number of lags for the variables. This choice is endorsed by several applied econometrics papers, i.e. Chudik et al. (2016), Kahn et al. (2019), Jarrett et al. (2019) and Mohaddes and Williams (2020).

Moreover, we add a cross-sectional augmentation of the dependent variable and the regressors to account for the presence of cross-sectional dependence and endogeneity in our data[6].

Following the literature, we assume that the error has a multi-factor structure

$$u_{i,t} = \lambda_i f_t + \varepsilon_{i,t}$$

where f_t are the unobserved common factors, λ_i are their loadings, and $\varepsilon_{i,t}$ is the serially uncorrelated idiosyncratic error with zero mean. Unobserved common factors can be seen as common global factors such as financial and economic crisis, energy market structural changes, technological progress. As proposed in Pesaran et al. (2015), we proxy the unobserved common factors term, $\lambda_i f_t$, with the cross-sectional average of the dependent variable and we deal with the cross-sectional dependence of regressors including their cross-sectional augmentation.

Finally, as in Jarrett et al. (2019) and Mohaddes and Williams (2020), we rely on the Pooled Mean Group estimator (PMG) because we are interested in estimating the long-run effect of energy price changes on economic growth in a specific set of countries rather than the individual long-run response of each country.

[6] Chudik et al. (2017) and Mohaddes and Raissi (2017) suggest a minimum of 25 continuous observations in time for each country are needed to estimate a panel CS-ARDL model without endogeneity problems.

We estimate the following panel CS-ARDL model for each cluster:

$$\Delta y_{i,t} = \alpha_i + \sum_{l=1}^{p} \gamma_{il} \Delta y_{i,t-l} + \sum_{l=0}^{p} \beta_l \Delta Pe_{t-l} + \sum_{l=0}^{p} \psi_l Vol_{t-l} + \sum_{l=0}^{p} \delta_{il} \Delta Inst_{i,t-l} + \sum_{l=0}^{p} \varphi_{il} \overline{x}_{i,t-l} + \varepsilon_{i,t} \quad (1)$$

where $\Delta y_{i,t}$ is growth rate of real GDP in country i at time t, α_i is the country-specific fixed effect, ΔPe_t is the growth rate of the energy price at time t, Vol_t is the energy price index volatility at time t, $\Delta Inst_{i,t}$ is the growth rate of the quality of institution index, $\overline{x}_{i,t-l}$ is the cross-sectional averages vector, i.e. $\overline{x}_{i,t} = \left(\overline{\Delta y}_{i,t}, \overline{\Delta Inst}_{i,t}\right)$, and $\varepsilon_{i,t}$ is the serially uncorrelated idiosyncratic error.

We compute the long-run Mean Group (MG) effects from the short-run coefficients in Equation 1, as in the following example:

$$\theta_i = \phi_{il}^{-1} \sum_{l=0}^{p} \beta_l$$

where $\phi_{il} = 1 - \sum_{l=1}^{p} \gamma_{il}$, which is the speed of adjustment[7]. Then, the long-run Pooled Mean Group (PMG) effects are obtained from the individual MG coefficients, restricting them to be the same for all countries within a cluster[8]. Indeed, we are interested in the long-run PMG effect concerning all countries within a cluster. Thus, we estimate the pooled long-run coefficients across the cross-sections while allowing the country-fixed effects and the short-run coefficients to vary. Consequently, each country has its unique residual variance and speed of adjustment.

Having controlled for common global factors, such as energy market structural changes over time, we ensure the reliability of our results and we can compare the long-run coefficients of each cluster, avoiding the normalization problem[9].
Moreover, we have performed our analysis on homogeneous clusters in terms of energy dependency, concerning net energy imports and total primary energy consumption, and in terms of level of development, due to the presence of the institutional quality variable in Equation 1. Finally, we have produced several robustness checks, estimating the model using the growth rate of GDP per capita as dependent variable (Subsection 4.3.2), using a different set of regressors (Subsection 4.3.1), and using an alternative clusterization (Subsection 4.3.3).

4.2 Empirical Results

We estimate Equation 1 on the whole sample and on the five sub-samples in which we have divided the countries using their degree of energy dependency, i.e. ED1, ED2, ED3, ED4, and ED5[10]. We report in the tables only the pooled long-run effects and the average speed of adjustment[7], namely $\widehat{\phi}$, because we are interested in the long-run growth effects, not in the short-run dynamics. Moreover, we exclude the cross-sectional augmented variables from the tables for clearance reasons, following other papers using our methodology.
We start by estimating the effect of an energy price increase on the GDP growth rate of countries dividing them in two groups only, based on their median degree of energy dependency over time. Therefore, countries whose median value is positive are in one group and the ones whose median is negative are in the other group. Broadly speaking, energy exporting countries in one cluster and energy importer ones in the other. As expected, we estimate an overall negative effect of an increase in the energy price on the long-run GDP growth rate. Among others, Berk and Yetkiner (2014) supports this result from an empirical and a theoretical point of view. Moreover, we find a positive effect of an increase in the

[7]The speed of adjustment is the speed at which an economic system converges to its long-run equilibrium. Therefore, it depends on the persistence of the explanatory variable, relying on the fact that the impact of a change in the explanatory variable takes time to work (Kydland and Prescott (1982)). For instance, a rise in income at time 0 may result in higher investments at time 1 that, in turn, can increase income at time 2. If the estimated speed of adjustment, namely $\hat{\phi}$, is negative and significant, the long-run relationship among the variables exists, as well as the adjustment process to the long-run equilibrium. In particular, if $-1 < \hat{\phi} < 0$ the adjustment is stable, if $\hat{\phi} = -1$ the adjustment takes place in 1 unit of time (a year, in our case), if $-2 < \hat{\phi} < -1$ the adjustment is overshooting. (Engle and Granger (1987), Kremers et al. (1992), Banerjee et al. (1993))

[8]Specifically, the PMG coefficients are calculated through a maximum likelihood approach using the Newton-Raphson numerical method.

[9]See Peersman and Van Robays (2012) for a discussion of the comparison of macroeconomic consequences of oil shocks across different countries.

[10]See Section 3.1 for an overview of the clusterization method and Table 8 for the list of countries within each group.

energy price on the GDP growth rate of countries with a negative degree of energy dependency and a negative one for countries with a positive degree of energy dependency (Table 10). Since these are straightforward results, we advance in our analysis by performing the regressions on the five groups of countries defined in Section 3.1.

Table 10: Long-Run Effects on the GDP per capita Growth Rate, 1971-2014

	GDP growth rate		
	Whole Sample	Energy Exporters	Energy Importers
Long-run			
ΔP_e	-0.0246***	0.0820***	-0.0271***
	(0.01)	(0.02)	(0.01)
$\Delta Inst$	0.0004	-0.0009	0.0009
	(0.00)	(0.00)	(0.00)
$\hat{\phi}$	-0.5552***	-0.5162***	-0.5602***
	(0.04)	(0.06)	(0.05)
Countries	48	16	32
Observations	1920	640	1280

Notes: The regression in Eq. 1 is performed on the whole sample and on energy exporting and energy importing countries. All estimations are obtained using the PMG estimator. Long-run coefficients and the error correction term, i.e. $\hat{\phi}$, are reported, while Short-run coefficients and the cross-sectionally augmented variables are included but not reported. The lag order is set to 3.
t statistics in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Overall, we note that the long-run effect of a positive change in the energy price growth rate on GDP growth rate is significantly different among clusters of energy dependency, and monotonically decreasing across quintiles. Table 11 shows that this effect ranges from being positive in major energy exporting countries, i.e. countries in ED1, to being negative in major energy importing countries, i.e. countries in ED5. Specifically, it is negative in the whole sample, namely -0.0308, but ranges from 0.1212 to -0.0882 across clusters, while remaining significant at the 1% level.
This is a relevant finding because it suggests that countries can reduce the long-run impact of energy price fluctuations on economic growth by changing their degree of energy dependency, moving from extreme quintiles to more central ones. For example, major energy importing countries may limit the negative effects of an energy price increase by reducing their degree of energy dependency, and major energy exporting countries may reduce the negative effect caused by a rise in energy price volatility.
Indeed, the latter countries suffer an adverse impact from increasing energy price volatility that is larger than the positive effect of a higher energy price. It is worth noting that the bigger size of the negative impact of volatility with respect to the positive effect of increasing energy price changes is supported by De V. Cavalcanti et al. (2015), Mohaddes and Raissi (2017) and Jarrett et al. (2019), but it is experienced only by major energy exporting countries - i.e. ED1 -, while the others are unaffected by volatility variations. This peculiar significant coefficient probably arise from the fact that a slight increase in energy price volatility can imbalance the public budget of some major energy exporting countries, but it can be easily absorbed by advanced countries that are typically richer and can count on robust contracts .
Moreover, we notice an overall positive effect of increasing institutions quality, which stands out for countries in ED3, probably due to the presence of emerging countries as India and Brazil. Finally, we show the cross-section dependence (CD) test (Pesaran et al. (2004), Pesaran (2015)) of residuals of the estimated regressions. The CD statistic is asymptotically distributed and it does not reject the null hypothesis of no cross-sectional dependence of errors.

With our long-run analysis, we contribute to the resource curse paradox literature, supporting the idea that fossil sources abundance does not damage economic growth, while an unwise management of these resources may lead to a negative outcome over time. Specifically, we show that the price volatility of resources harms long-run growth, as suggested by several recent studies (De V. Cavalcanti et al.

Table 11: Long-Run Effects on the GDP Growth Rate, 1971-2014

	GDP growth rate					
	Whole Sample	ED1	ED2	ED3	ED4	ED5
Long-run						
ΔP_e	-0.0250***	0.0998***	0.0581***	-0.0106	-0.0384***	-0.0602***
	(0.01)	(0.03)	(0.02)	(0.01)	(0.01)	(0.01)
Vol	-0.0088	-0.1775**	0.0179	-0.0336	-0.0098	-0.0017
	(0.01)	(0.07)	(0.04)	(0.03)	(0.03)	(0.03)
$\Delta Inst$	0.0021***	0.0020	-0.0018	0.0033***	-0.0010	0.0007
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\hat{\phi}$	-0.5256***	-0.5268***	-0.4497***	-0.6572***	-0.5458***	-0.4744***
	(0.04)	(0.09)	(0.07)	(0.07)	(0.07)	(0.10)
CD test statistic	4.24***	-3.09***	-2.51**	-1.54*	-2.26***	-3.49***
Countries	48	9	10	10	10	9
Observations	1872	351	390	390	390	351

Notes: The regression in Eq. 1 is performed on the whole sample and on several sub-samples, i.e. ED1, ED2, ED3, ED4 and ED5. Countries are divided in five clusters (ED1, ED2, ED3, ED4 and ED5) on the basis of their degree of energy dependency over time, as explained in Section 3.1. All estimations are obtained using the PMG estimator. Long-run coefficients and the error correction term, i.e. $\hat{\phi}$, are reported, while Short-run coefficients and the cross-sectionally augmented variables are included but not reported. The lag order is set to 3.
t statistics in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

(2015), Mohaddes and Raissi (2017) and Jarrett et al. (2019)). These studies also recommend a better quality of institutions and the correct use of sovereign wealth funds as main strategies to limit the price volatility negative effects. Following this advice, major energy exporting countries could rely less on produced quantity adjustments to counterbalance government budget losses.
Furthermore, we show that only countries with an unbalanced degree of energy dependency, either being major exporters or importers of energy commodities, are significantly influenced by energy price changes, thus narrowing the economic and political debate around this issue. Only countries having a degree of energy dependency which is above a certain threshold should be concerned about that. For example, energy dependency is and has been an important political issue in the US, but the USA is clustered as an energy balanced country, so they do not suffer an energy dependency effect.

If we exclude the energy price volatility from Equation 1 and we re-estimate the model on the whole sample and on the five clusters of energy dependency, we still see that countries in ED1 benefit from increasing energy price in the long-run, while countries in ED5 are hit by this change, and countries in ED3 remains unaffected. This finding is consistent with our robustness checks (Section 4.3).

Table 12: Long-Run Effects on the GDP Growth Rate, 1971-2014

	GDP growth rate					
	Whole Sample	ED1	ED2	ED3	ED4	ED5
Long-run						
ΔP_e	-0.0308***	0.1212***	-0.0366***	-0.0073	-0.0239*	-0.0882***
	(0.01)	(0.04)	(0.01)	(0.01)	(0.01)	(0.02)
$\Delta Inst$	0.0007	-0.0008	-0.0013	0.0024***	-0.0025	0.0019
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\hat{\phi}$	-0.5747***	-0.5399***	-0.5717***	-0.7723***	-0.5556***	-0.4717***
	(0.04)	(0.09)	(0.09)	(0.07)	(0.06)	(0.10)
CD test statistic	4.01***	-3.24***	-2.33*	-2.26*	-2.55**	-3.51***
Countries	48	9	10	10	10	9
Observations	1920	360	400	400	400	360

Notes: The regression in Eq. 1 is performed on the whole sample and on several sub-samples, i.e. ED1, ED2, ED3, ED4 and ED5. Countries are divided in five clusters (ED1, ED2, ED3, ED4 and ED5) on the basis of their degree of energy dependency over time, as explained in Section 3.1. All estimations are obtained using the PMG estimator. Long-run coefficients and the error correction term, i.e. $\hat{\phi}$, are reported, while Short-run coefficients and the cross-sectionally augmented variables are included but not reported. The lag order is set to 3.
t statistics in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

4.3 Robustness Checks

To ensure the robustness of our results, we provide various versions of the main regression, using the growth rate of GDP per capita as dependent variable, replacing the institutional quality variable with a political stability variable, excluding the energy price volatility, and using a different clusterization based on quartiles of energy dependency.

4.3.1 Political Quality

In Table 13, we substitute the institutional quality variable with the political quality variable. It is worth noting that the two variables are not highly correlated (Table 6) supporting the relevance of this robustness check. We see that our main finding, the monotonically decreasing long-run effects of energy price change on GDP growth across quintiles, still holds, although we note some relevant differences with Table 11. These differences may suggest that institution quality and political quality do not perfectly substitute each other and that the institution quality variable is more suitable for our analysis. Indeed, the resource curse paradox literature extensively relies on the latter variable.
Furthermore, we see that being in ED2 is the best possible choice since both energy price and energy price volatility cause a positive long-run effect on growth. Countries in ED3 experience a positive effect due to energy price changes but they cannot exploit a positive effect from volatility, while countries in ED5 can. This is an unexpected finding, which is probably due to the high income and level of development of major energy importing countries, giving them the chance to cope with volatility through proper management of energy derivatives and supply contracts. However, assuming that there is no non-linearity in the energy price effect, being in ED4 is preferable since this profile of energy dependency guarantees being unaffected by energy price upward and downward movements.

4.3.2 GDP per capita as dependent variable

In Table 14 we use the growth rate of GDP per capita as dependent variable, and we note that (i) our contribution to the resource curse paradox is confirmed, however, the volatility negative effect is much lower, (ii) countries in ED5 are still relevantly negatively affected by rising energy prices, (iii) countries in ED3 are negatively affected by energy price rising and energy price volatility, (iv) ED2 and ED4 are

Table 13: Long-Run Effects on the GDP Growth Rate, 1971-2014

	GDP growth rate					
	Whole Sample	ED1	ED2	ED3	ED4	ED5
Long-run						
ΔP_e	-0.0094**	0.1328***	0.0432***	0.0313**	-0.0099	-0.0206***
	(0.00)	(0.03)	(0.01)	(0.02)	(0.01)	(0.01)
Vol	0.0214**	-0.1839***	0.0865***	0.0338	0.0178	0.0198*
	(0.01)	(0.07)	(0.02)	(0.03)	(0.02)	(0.01)
ΔPol	0.0009*	-0.0006	0.0024**	0.0009	0.0010	-0.0006
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\hat{\phi}$	-0.7645***	-0.7133***	-0.7972***	-0.7480***	-0.6727***	-0.8789***
	(0.06)	(0.08)	(0.15)	(0.10)	(0.14)	(0.20)
Countries	42	9	10	10	10	9
Observations	1680	329	369	333	353	296

Notes: The regression in Eq. 1 is performed on the whole sample and on several sub-samples, i.e. ED1, ED2, ED3, ED4 and ED5. Countries are divided in five clusters (ED1, ED2, ED3, ED4 and ED5) on the basis of their degree of energy dependency over time, as explained in Section 3.1. All estimations are obtained using the PMG estimator. Long-run coefficients and the error correction term, i.e. $\hat{\phi}$, are reported, while Short-run coefficients and the cross-sectionally augmented variables are included but not reported. The lag order is set to 3.
t statistics in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

not negatively affected by energy price increase nor by energy price volatility. All these findings suggest that countries in ED3 are vulnerable to energy price changes, in contrast with what was previously found. However, moving from extreme degrees of energy dependency to more moderate degrees can off-set the negative long-run effects of energy price fluctuations, i.e. from ED5 to ED4 or from ED1 to ED2.
These findings remain consistent even if we exclude volatility from this specification (Table 15). Moreover, the unexpected negative effect of increasing energy price disappears for countries in ED3.
Thus, we still suggest that having a moderate degree of energy dependency is the most suitable strategy.

4.3.3 Alternative Clusterization: Quartiles of Energy Dependency

If we rely on the alternative clusterization based on quartiles of energy dependency, we still see that (i) countries in the first quartile are positively influenced by increasing energy price changes and negatively hit by increasing energy price volatility, (ii) the latter effect is bigger than the first one, (iii) countries in the last quartile are negatively influenced by energy price increases, (iv) countries in central quartiles are unaffected by energy price but exporters experience price volatility negative effect. Bullet points (i) and (ii) hold in all specifications using quartiles of energy dependency (Tables 16, 17, 18 and 19).
Overall, these results are consistent with the ones obtained using quintiles of energy dependency, suggesting that a balanced profile of energy dependency is preferable.

Table 14: Long-Run Effects on the GDP per capita Growth Rate, 1971-2014

	GDP per capita growth rate					
	Whole Sample	ED1	ED2	ED3	ED4	ED5
Long-run						
ΔP_e	-0.0217***	0.1040***	0.1000***	-0.0205*	-0.0012	-0.0625***
	(0.01)	(0.03)	(0.02)	(0.01)	(0.02)	(0.02)
Vol	-0.0383**	-0.2038**	-0.0199	-0.0680*	-0.0114	-0.0323
	(0.02)	(0.08)	(0.06)	(0.04)	(0.04)	(0.04)
$\Delta Inst$	0.0021***	0.0020	-0.0024	0.0034***	-0.0058***	0.0011
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\hat{\phi}$	-0.4937***	-0.4954***	-0.4254***	-0.6004***	-0.5195***	-0.4679***
	(0.04)	(0.07)	(0.10)	(0.08)	(0.07)	(0.11)
Countries	48	9	10	10	10	9
Observations	1872	351	390	390	390	351

Notes: The regression in Eq. 1 is performed on the whole sample and on several sub-samples, i.e. ED1, ED2, ED3, ED4 and ED5. Countries are divided in five clusters (ED1, ED2, ED3, ED4 and ED5) on the basis of their degree of energy dependency over time, as explained in Section 3.1. All estimations are obtained using the PMG estimator. Long-run coefficients and the error correction term, i.e. $\hat{\phi}$, are reported, while Short-run coefficients and the cross-sectionally augmented variables are included but not reported. The lag order is set to 3.
t statistics in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Table 15: Long-Run Effects on the GDP per capita Growth Rate, 1971-2014

	GDP per capita growth rate					
	Whole Sample	ED1	ED2	ED3	ED4	ED5
Long-run						
ΔP_e	-0.0246***	0.1149***	-0.0271**	-0.0104	0.0022	-0.0735***
	(0.01)	(0.03)	(0.01)	(0.01)	(0.01)	(0.02)
$\Delta Inst$	0.0004	-0.0009	-0.0010	0.0021***	-0.0055***	0.0015
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\hat{\phi}$	-0.5552***	-0.5365***	-0.5464***	-0.7123***	-0.5415***	-0.5125***
	(0.04)	(0.06)	(0.08)	(0.07)	(0.05)	(0.13)
Countries	48	9	10	10	10	9
Observations	1920	360	400	400	400	360

Notes: The regression in Eq. 1 is performed on the whole sample and on several sub-samples, i.e. ED1, ED2, ED3, ED4 and ED5. Countries are divided in five clusters (ED1, ED2, ED3, ED4 and ED5) on the basis of their degree of energy dependency over time, as explained in Section 3.1. All estimations are obtained using the PMG estimator. Long-run coefficients and the error correction term, i.e. $\hat{\phi}$, are reported, while Short-run coefficients and the cross-sectionally augmented variables are included but not reported. The lag order is set to 3.
t statistics in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Table 16: Long-Run Effects on the GDP Growth Rate, 1971-2014

	GDP growth rate				
	Whole Sample	ED1	ED2	ED3	ED4
Long-run					
ΔP_e	-0.0250***	0.0946***	-0.0108	-0.0168	-0.0540***
	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)
Vol	-0.0088	-0.1424***	-0.0863**	0.0071	0.0031
	(0.01)	(0.05)	(0.04)	(0.03)	(0.03)
$\Delta Inst$	0.0021***	0.0011	0.0030***	0.0023	0.0004
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\hat{\phi}$	-0.5256***	-0.5060***	-0.4898***	-0.5917***	-0.4882***
	(0.04)	(0.08)	(0.06)	(0.08)	(0.09)
Countries	48	13	12	13	10
Observations	1872	507	468	507	390

Notes: The regression in Eq. 1 is performed on the whole sample and on several sub-samples, i.e. ED1, ED2, ED3, and ED4. Countries are divided in five clusters (ED1, ED2, ED3, and ED4) on the basis of their degree of energy dependency over time, as explained in Section 3.1. All estimations are obtained using the PMG estimator. Long-run coefficients and the error correction term, i.e. $\hat{\phi}$, are reported, while Short-run coefficients and the cross-sectionally augmented variables are included but not reported. The lag order is set to 3.
t statistics in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Table 17: Long-Run Effects on the GDP per capita Growth Rate, 1971-2014

	GDP per capita growth rate				
	Whole Sample	ED1	ED2	ED3	ED4
Long-run					
ΔP_e	-0.0217***	0.1061***	-0.0281**	-0.0003	-0.0579***
	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)
Vol	-0.0383**	-0.1075**	-0.1190**	-0.0064	-0.0255
	(0.02)	(0.05)	(0.05)	(0.04)	(0.04)
$\Delta Inst$	0.0021***	0.0004	0.0034***	0.0011	0.0008
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\hat{\phi}$	-0.4937***	-0.5260***	-0.4161***	-0.5654***	-0.4579***
	(0.04)	(0.08)	(0.06)	(0.08)	(0.10)
Countries	48	13	12	13	10
Observations	1872	507	468	507	390

Notes: The regression in Eq. 1 is performed on the whole sample and on several sub-samples, i.e. ED1, ED2, ED3, and ED4. Countries are divided in five clusters (ED1, ED2, ED3, and ED4) on the basis of their degree of energy dependency over time, as explained in Section 3.1. All estimations are obtained using the PMG estimator. Long-run coefficients and the error correction term, i.e. $\hat{\phi}$, are reported, while Short-run coefficients and the cross-sectionally augmented variables are included but not reported. The lag order is set to 3.
t statistics in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Table 18: Long-Run Effects on the GDP Growth Rate, 1971-2014

	GDP growth rate				
	Whole Sample	ED1	ED2	ED3	ED4
Long-run					
ΔP_e	-0.0308***	0.1086***	-0.0255**	-0.0088	-0.0781***
	(0.01)	(0.03)	(0.01)	(0.01)	(0.02)
$\Delta Inst$	0.0007	-0.0001	0.0013	0.0016	0.0014
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\hat{\phi}$	-0.5747***	-0.4997***	-0.6269***	-0.6309***	-0.4643***
	(0.04)	(0.08)	(0.06)	(0.08)	(0.10)
Countries	48	13	12	13	10
Observations	1920	520	480	520	400

Notes: The regression in Eq. 1 is performed on the whole sample and on several sub-samples, i.e. ED1, ED2, ED3, and ED4. Countries are divided in five clusters (ED1, ED2, ED3, and ED4) on the basis of their degree of energy dependency over time, as explained in Section 3.1. All estimations are obtained using the PMG estimator. Long-run coefficients and the error correction term, i.e. $\hat{\phi}$, are reported, while Short-run coefficients and the cross-sectionally augmented variables are included but not reported. The lag order is set to 3.
t statistics in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Table 19: Long-Run Effects on the GDP per capita Growth Rate, 1971-2014

	GDP per capita growth rate				
	Whole Sample	ED1	ED2	ED3	ED4
Long-run					
ΔP_e	-0.0246***	0.1048***	-0.0257**	0.0073	-0.0702***
	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)
$\Delta Inst$	0.0004	-0.0005	0.0016	0.0007	0.0013
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\hat{\phi}$	-0.5552***	-0.5382***	-0.5619***	-0.6039***	-0.4818***
	(0.04)	(0.07)	(0.06)	(0.07)	(0.12)
Countries	48	13	12	13	10
Observations	1920	520	480	520	400

Notes: The regression in Eq. 1 is performed on the whole sample and on several sub-samples, i.e. ED1, ED2, ED3, and ED4. Countries are divided in five clusters (ED1, ED2, ED3, and ED4) on the basis of their degree of energy dependency over time, as explained in Section 3.1. All estimations are obtained using the PMG estimator. Long-run coefficients and the error correction term, i.e. $\hat{\phi}$, are reported, while Short-run coefficients and the cross-sectionally augmented variables are included but not reported. The lag order is set to 3.
t statistics in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

5 Conclusion

In this empirical work, we study whether the long-run growth of countries differ depending on a country's degree of energy dependency. Indeed, energy dependency is a great concern for most countries because of its implications on energy security and growth. Specifically, we study the long-run impact of energy price changes on long-run GDP growth.

There are two novel aspects in this paper. First, all energy commodities are considered, not only oil, and second, our work goes beyond the standard distinction between oil importing and exporting countries. Then, we verify whether the long-run effects of oil price changes differ depending on a country's degree of energy dependency, using a cross-sectionally augmented panel autoregressive distributed lag (CS-ARDL) approach in 48 countries from 1971 to 2014. We have decided to cluster the countries in five groups based on their degree of energy dependency, arguing that the division in energy exporting and importing countries does not define homogeneous clusters. The two main sources of heterogeneity are the level of development[11], and the relevant differences in terms of energy dependency among countries within the same sub-sample. For instance, Italy and the US are net energy importers, but Italy imports 80% of its total primary energy consumption while the US imports just about 10%.

Our panel approach suggests that energy price changes have negative effects on the economic growth of countries with a high degree of energy dependency and that countries with a low degree of energy dependency benefit from increasing energy price, while being damaged by its volatility. This analysis contributes to the resource curse paradox literature supporting the idea that the long-run economic growth of resource-rich countries is harmed by resource price volatility, not by abundance per se, as in De V. Cavalcanti et al. (2011), De V. Cavalcanti et al. (2015), Mohaddes and Pesaran (2016), Jarrett et al. (2019) and Van Eyden et al. (2019). Moreover, this analysis shows that major importing and exporting countries are the most affected countries, supporting the idea that a balanced energy dependency is preferable. Indeed, we show that the degree of energy dependency becomes a relevant factor in the estimation of energy price changes impact only beyond a certain threshold. However, it must be said that our main model captures the impact of an increase in the energy price or in the energy price volatility, but it may not properly fit to estimation of the impact of abrupt and lasting energy price or energy price volatility changes. Regime-changes and threshold models are more fitting in those cases.

An interesting future development of the main model could be a Dynamic Panel Quantile Model, as in Harding et al. (2020), but adapting it to a panel CS-ARDL framework. This could permit to avoid the ex-ante clusterization of the sample, while maintaining the actual long-run multi-country approach. Otherwise, it could be interesting to estimate a Dynamic Panel Threshold Model (Chudik et al. (2017)) to empirically find the existence of an energy dependency threshold and to quantify the coefficients change above and beyond this threshold.

Overall, we find that countries with a more balanced energy dependency seem to be less affected or not at all by energy price fluctuations and energy price volatility in the long-run.

These results have several policy implications. If energy exporting countries were able to limit the negative effects of energy price volatility, for example working on their financial institutions (i.e. sovereign wealth funds) as suggested by Jarrett et al. (2019) and Mohaddes and Raissi (2017), they will significantly improve their macroeconomic stability conditions without extensively relying on adjustments in energy production. The stabilization of global energy production from fossil sources would improve the global energy security conditions with noticeable geopolitical advantages. Another suggested policy for major energy exporting countries refers to the diversification of the energy production sector via renewable sources. This strategic choice should allow them to continue to play a pivotal role in the global energy supplier market in light of a transitioning world. On the other side, major energy importers may reduce their degree of energy dependency augmenting renewable energy production to diversify their energy mix and augment their own energy production while reducing their energy consumption via increasing energy efficiency and decreasing energy intensity.

These changes would enhance a more competitive and diversified energy sector and a lower global energy per capita utilisation, diminishing the vulnerability of countries to energy price and supply shocks. Finally, a key implication that emerges is that converging to a balanced degree of energy dependency through the above-mentioned energy policies have important consequences on energy-related emissions and thus on climate change. Indeed, significant shifts from a high degree of energy dependence to a moderate energy dependency may be possible only through major changes toward less carbon intensive economies and an effective energy transition at the global level.

[11] Energy exporting countries are mainly emerging countries with the exceptions of Canada, Australia, and Norway, while energy importing countries are mostly developed countries with the exceptions of Chile, India, Senegal, and Brazil.

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Appendices

A An Alternative Model using the Energy Dependency Index

For completeness, we show the results obtained using a panel CS-ARDL model that embeds the Energy Dependency Index as an explanatory variable. From Table A1, it is possible to see that the energy dependency index does not have a direct effect on growth, but these effects appear when it is interacted. This finding supports the idea that the Energy Dependency Index is a suitable variable to cluster countries because it is no explanatory power and a small variability over time and countries. In addition, this finding implies that the clusterization of countries is necessary to appreciate the heterogeneous long-run effects on growth of changes in the energy price index and in its volatility, as shown in Section 4.2.

$$\begin{aligned}\Delta y_{i,t} = \alpha_i + \sum_{l=1}^{p} \gamma_{il} \Delta y_{i,t-l} + \sum_{l=0}^{p} \delta_{il} \Delta ED_{i,t-l} + \sum_{l=0}^{p} \beta_l \Delta Pe_{t-l} + \sum_{l=0}^{p} \psi_{il} (\Delta Pe_{t-l} \times ED_{i,t-l}) + \\ + \sum_{l=0}^{p} \eta_{il} (Vol_{t-l} \times ED_{i,t-l}) + \sum_{l=0}^{p} \varphi_{il} \overline{\Delta y}_{i,t-l} + \varepsilon_{i,t}\end{aligned} \quad (2)$$

where $\Delta y_{i,t}$ is growth rate of real GDP in country i at time t, α_i is the country-specific fixed effect, $ED_{i,t-l}$ is the energy dependency index in country i at time t, ΔPe_t is the growth rate of the energy price at time t, Vol_t is the energy price index volatility at time t, $\overline{\Delta y}_{i,t-l}$ is the cross-sectional average of the GDP growth rate, and $\varepsilon_{i,t}$ is the serially uncorrelated idiosyncratic error. $\Delta Pe_{t-l} \times ED_{i,t-l}$ and $Vol_{t-l} \times ED_{i,t-l}$ are the interaction terms.

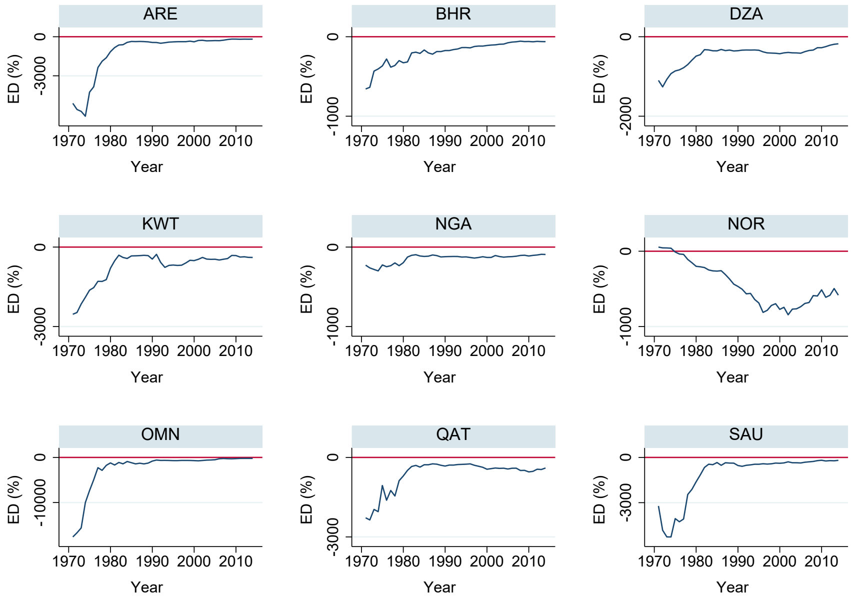
Table A1: Long-Run Effects on the GDP Growth Rate using the Energy Dependency Index, 1971-2014

	GDP growth rate			
	(1)	(2)	(3)	(4)
Long-run				
ED	0.0000	0.0000	-0.0000	
	(0.0013)	(0.0000)	(0.0000)	
ΔP_e		-0.0089	-0.0194***	-0.0267***
		(0.0066)	(0.0065)	(0.0060)
$\Delta P_e \times ED$		-0.0002**	-0.0002***	-0.0001**
		(0.0001)	(0.0001)	(0.0000)
$Vol \times ED$		-0.0000		
		(0.0001)		
$\hat{\phi}$	-0.8802***	-0.5943***	-0.6251***	-0.6122***
	(0.0465)	(0.0426)	(0.0406)	(0.0407)
Observations	1920	1920	1920	1920
Countries	48	48	48	48

Notes: The regression in Eq. 2 is performed on the whole sample of countries. All estimations are obtained using the PMG estimator. Long-run coefficients and the error correction term, i.e. $\hat{\phi}$, are reported, while Short-run coefficients and the cross-sectionally augmented variables are included but not reported. The lag order is set to 3.
t statistics in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

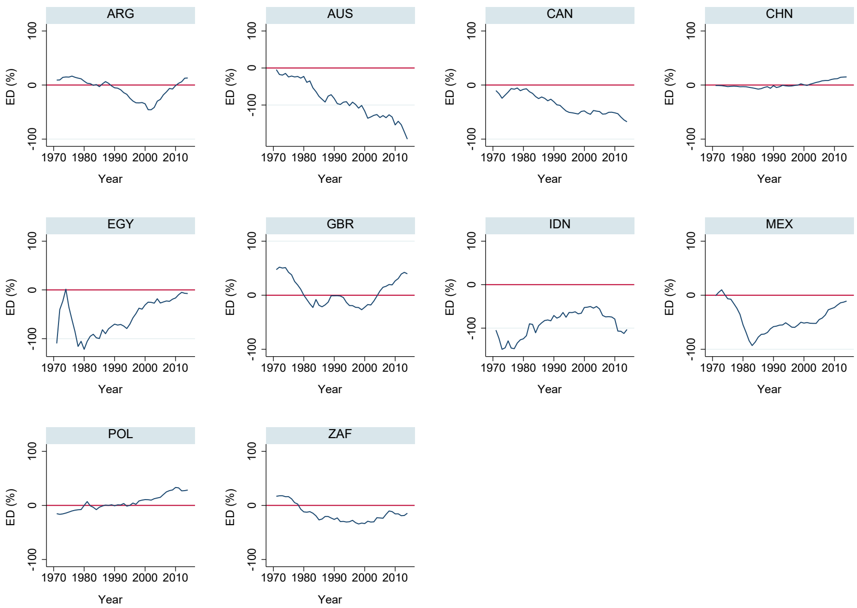
B The Degree of Energy Dependency of the considered countries

Figure B1: The Degree of Energy Dependency (Cluster ED1)



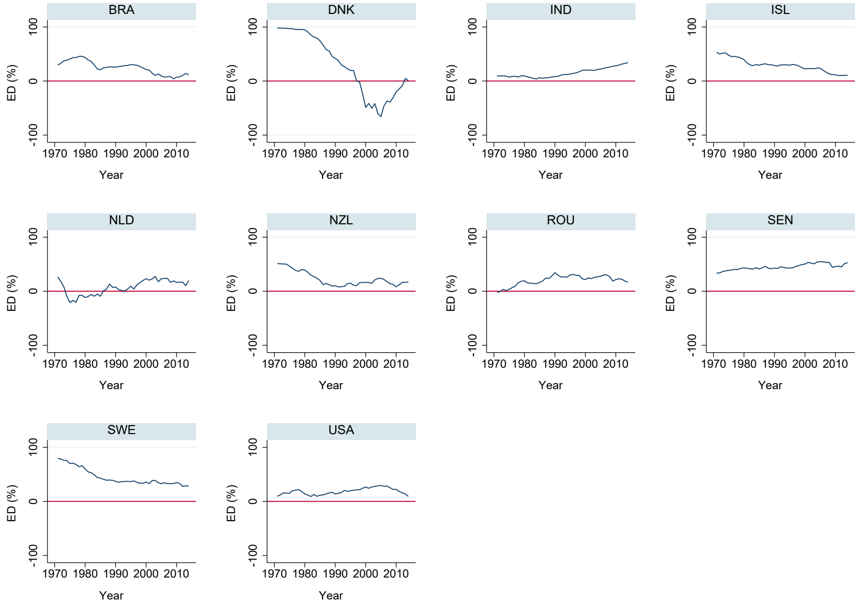
Notes: Countries with a very low degree of energy dependency, i.e. countries composing the cluster ED1. "ED (%)" stands for Energy Dependency Index.

Figure B2: The Degree of Energy Dependency (Cluster ED2)



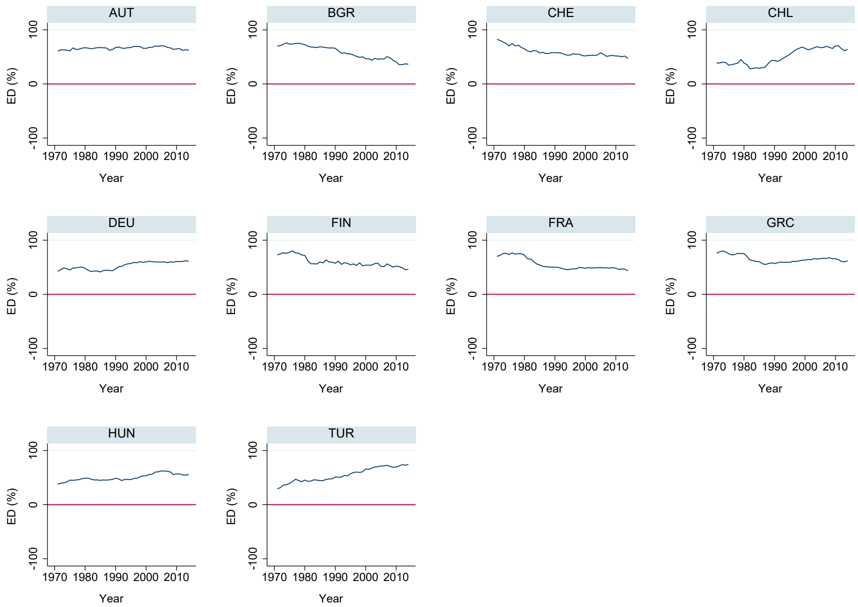
Notes: Countries with a low degree of energy dependency, i.e. countries composing the cluster ED2. "ED (%)" stands for Energy Dependency Index.

Figure B3: The Degree of Energy Dependency (Cluster ED3)



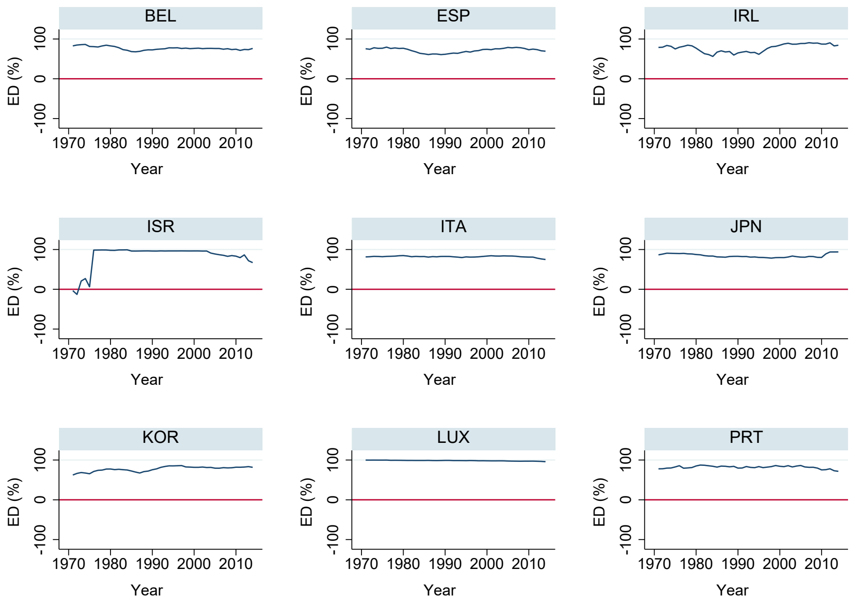
Notes: Countries with a balanced degree of energy dependency, i.e. countries composing the cluster ED3. "ED (%)" stands for Energy Dependency Index.

Figure B4: The Degree of Energy Dependency (Cluster ED4)



Notes: Countries with a high degree of energy dependency, i.e. countries composing the cluster ED4. "ED (%)" stands for Energy Dependency Index.

Figure B5: The Degree of Energy Dependency (Cluster ED5)



Notes: Countries with a very high degree of energy dependency, i.e. countries composing the cluster ED5. "ED (%)" stands for Energy Dependency Index.

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