## ABSTRACT

This study examines the impact of infrastructure-damaging natural disasters (meteorological and geophysical disasters) on energy consumption differentiating by type of energy- residential vs. industrial and non-renewable vs. renewable. We use a novel comprehensive unbalanced data set spanning fifty years (1961-2011) for up to 80 countries, which we group by level of development to reduce heterogeneity within the group. We apply an estimation method that takes into account the dynamics of the economic processes in the panel - the Blundell and Bond GMM estimator. For High income economies, which are also technologically the most advanced, we are able to demonstrate a positive impact on renewable energy use five years after the occurrence of a geophysical disaster. For Low Income economies we observe positive effects on industrial energy consumption; for Middle Income countries, on residential energy consumption.

## 1. Introduction

Natural disasters have complex short-run and long-run impacts on energy use. This study examines their direct impact on energy consumption as a consequence of infrastructure destruction, and the longer-run impacts during the period of economic reconstruction. Using a comprehensive 80-country data set spanning a period of 50 years, we are able to identify differences in energy use patterns across sectors (industrial and commercial vs. residential), levels of economic development (Low Income, Middle Income and High Income countries), and the nature of the natural disaster (geophysical, climate, and meteorological). This study further explores the opportunities created by post-disaster economic reconstruction to shift from conventional fossil fuels to renewable energy sources.

While it is expected for natural disasters to have negative imminent effects on energy consumption as they destroy infrastructure, including energy grids, destruct the work of oil refineries, and renewable energy-producing plants, we hypothesize that the lagged effect of a disaster (we study five year lags) could be either positive or negative and we are most interested with whether there is evidence of upgrading to renewable energy consumption with the process

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of rebuilding. Indeed, we are able to demonstrate that for high income economies, which are also technologically the most advanced, five years after the geophysical disaster striking, we observe that it produces a positive impact on renewable energy use. For less developed countries, we observe positive effects of geological disasters on Industrial Energy Consumption, in the case of low income economies, and residential energy, in the case of middle income countries. This overwhelmingly positive impact of lagged geophysical disasters on energy use, despite their immediate negative effect, reflects the process of reconstruction. The impact on renewable energy use suggests that post-disaster reconstruction provides the opportunity to decouple economic activity from the carbon footprint. The long-run relationship between disaster recovery and patterns of energy demand merits continued study.

The current literature frames the impact of natural disasters on GDP in terms of two alternative hypotheses. First, “Creative destruction” leads to capital upgrading, as infrastructure that has been destroyed during a natural disaster is rebuilt (see Skidmore and Toya [1]; Hallegatte and Dumas [2]; and Noy and Vu [3]). The second hypothesis that the economic slowdown associated with a natural disaster is followed, at best, by convergence to pre-disaster levels (see Smith et al. [4]; Vigdor [5]; Belasen and Polachek [6] and [7]; Hornebeck [8]; Strobl [9]; and Boustan, Khan and Rhode [10].) We extend the above literature that has explored the impact of natural disasters on GDP, to study the impact of natural disasters on energy consumption in the short- and long-run. Our study fits with the first stream of literature finding a recovery from disasters over time. We find broad evidence that although the immediate impact of meteorological and geophysical disasters on energy consumption is negative, in the long run, signs of recovery appear. We chose the methodology or the Blundell-Bond GMM estimator (Arellano and Bover [11]; Blundell and Bond [12]) in order to be able to exploit both the time series dynamics and the pooled country characteristics of the data, while controlling for endogeneity.

The research presented in this paper draws on three related threads: 1) the macroeconomic impacts of natural disasters; 2) the relationship between energy security and economic development; and 3) the relationship between natural disasters and energy demand

## 1.1. The macroeconomic impacts of natural disasters.

Noy [13] is one of the first efforts to systematically model the macroeconomic impacts of natural disasters. Noy shows “[c]ountries with a higher literacy rate, better institutions, higher per capita income, higher degree of openness to trade, and higher levels of government spending are better able to withstand the initial disaster shock and prevent further spillovers into the macroeconomy.”

Noy and Yonson [14] draw a useful distinction between vulnerability and resilience. “[V]ulnerability is typically linked to prevention, preparedness, and mitigation; while resilience, to rehabilitation, reconstruction, and recovery.” Vulnerability is a function of the nature of hazards, the population at risk, and the process of urban development within the expected path of natural and anthropogenic disasters. The Disaster Risk Index is an effort to capture the factors that affect risk on a country scale. Resilience is a function of the economic, social and political institutions that enable a country to recover from disaster.

Lazzaroni and van Bergeijk [15] present the results of a meta-analysis of 64 primary studies of the macroeconomic impacts of natural disasters conducted between 2000 and 2013, examining both the direct costs and indirect costs imposed by natural disasters. Direct costs are defined as those that occur at the time of the incident, including loss of infrastructure, goods and services, and the number of people affected, including injury and mortality. Indirect and secondary costs are defined as the losses attributable to “destruction or business interruptions and effects on the performance of the overall economy.” The authors suggest that “future studies on the macroeconomic impact of disasters should explore more often the mitigation role of education, investment and openness by including these as explanatory variables.”

Toya and Skidmore [16] address the relationship between economic development and macroeconomic vulnerability to natural disasters. The authors find countries with higher income, higher educational attainment, more openness and more developed financial institutions experience fewer disaster-related losses.

Kellenberg and Mobarak [17] further explore the relationship between economic development and macroeconomic vulnerability to natural disasters. The paper challenges the posited inverse relationship between the level of development and the magnitude of disaster-related damages. They present evidence for a Kuznets inverted-u relationship, in which disaster deaths increase with per-capita income up to a level of approximately $4,500 - $5,500, and decrease with per-capita income beyond that inflection point.

Fomby et al. [18] traces the response of GDP growth over time in the wake of a natural disaster. The authors report that the impact of natural disasters is more severe for developing countries than for industrialized countries. The GDP response varies with the type of disaster and economic sector (agricultural vs. non-agricultural). For example, droughts have an immediate impact on agricultural output, while they effect the non-agricultural economy with a time lag. Floods and earthquakes have a positive impact over time, as they stimulate reconstruction activities.

Most of the studies of the macroeconomic impact of disasters rely on the EM-DAT or similar databases, which measure the economic impact of disasters. Felbermayr and Gröschl [19] merges data on disaster intensity with EM-DAT data on disaster impacts to create measures of the severity of disasters that are not correlated with GDP. Using their GeoMet data, the authors find a “substantial negative and robust average impact effect of disasters on growth.” In particular, they estimate that the most severe 5% disaster years are associated with a reduction in GDP growth of upwards of 0.46%.

### 1.2 Energy security and economic development.

Modern industrial economies are fueled by a secure supply of affordable energy resources. Constantini and Martini [20] explore the relationship between energy and the economy for a panel of developed and developing countries. A Granger-causality framework failed to detect a consistent pattern of causality across countries, sectors, and time (short-run vs. long-run). In the industrial sector, for example the short-run direction of causality was from industrial production to energy demand; in the long run this same pattern was detected for the non-OECD panel, whereas for the OECD countries the causality ran from energy demand to industrial output, perhaps reflecting energy conservation investments in that sector.

At the same time, Narayan and Doytch [21] and Doytch and Narayan [22] investigate the renewable and non-renewable energy consumption and economic growth nexus in the industrial and residential energy sectors. The authors find support of the feedback hypothesis (a bidirectional causation between economic growth and energy consumption), the growth hypothesis (a unidirectional causation flowing from energy consumption to economic growth) and conservative hypothesis (unidirectional causation flowing from economic growth to energy) when examining non-renewables, both in terms of total and industrial energy consumption. With respect to consumption of renewables, they find that it is mostly neutral with respect to economic growth.

Huang, et al. [23] uses a panel of 82 countries for the 1972-2002 period to model the relationship between energy consumption and GDP. The causal relationship between energy demand and GDP growth is tested for the four income groups as defined by the World Bank (low income, lower middle income, upper middle income, and high income.) There results are suggestive of the environmental Kuznets curve: for low income countries there is no relationship between energy and GDP growth; for lower middle and upper middle income countries GDP growth drives energy demand. For high-income countries, there is an inverse relationship between energy GDP growth and energy demand. The paper explores the energy and environmental policy implications of these findings.

Apergis and Tang [24] test the energy-led growth hypothesis for a panel of 85 countries. The authors posit that if energy consumption Granger-causes GDP growth, environmental policies based on energy conservation will have a negative economic impact. In contrast, if GDP growth Granger-causes energy consumption, energy conservation strategies can reduce energy demand (and pollution) without reducing GDP growth. The key finding is that the economies of lower middle, upper middle and high income countries are reliant on capital-intensive sectors, and hence energy dependent. These countries support the energy-led growth hypothesis; energy-conservation policies directed at climate change are more likely to reduce economic growth.

Pao, et al. [25], based on earlier work by Apergis and Payne [26] (see references cited in Pao, et al. [25], Table 1), tests the relationship between clean energy (renewables and nuclear energy) and non-clean energy (fossil fuels), and the relationship between renewable energy and economic growth. Among a broader set of empirical results, they find a long-run unidirectional causality between renewable energy demand and economic growth. One possible explanation for this finding is that the shift from fossil fuels to renewable energy is connected to changes in sectoral composition of output (from heavy industry to light manufacturing and services) as well as well as more modern technologies.

### 1.3. Natural disasters and energy demand.

Two issues that fall broadly within the framework of energy security are: 1, how do disasters impact energy supply and demand; and 2, what can we do to make the energy sector more resilient – i.e., to assure reliable energy supplies in the wake of a disaster.

In the short run, natural disasters reduce manufactured capital (buildings and infrastructure) and natural capital (e.g., coastal wetlands, forests and agricultural lands). In the longer-run, disasters may serve as an economic stimulus through the reconstruction of manufactured and natural capital stocks. To the extent that the capital stocks are replaced by capital that embodies newer technologies, this Shumpeterian "creative destruction" may make the economy more energy efficient (Crespo Cuaresma et al. [27]). This is referred to as the "productivity effect" (see Hallegatte and Dumas [2] and references cited therein). Hallegatte and Dumas [2] estimate a Solow-type growth model, in which the short-run impact of natural disaster is captured by a parameter which represents the fraction of capital stock destroyed, and a capital vintage model captures the replacement of all or part of capital stock destroyed by capital of the current vintage. This model has implications for both the energy intensity and fuel mix of production in the post-disaster period. However this study does not explicitly address these questions.

## 2. Model and Methodology

To determine the impact of natural disasters on energy consumption we run two models: 1, a contemporaneous model, where we account for disasters of the same time period as energy consumption indicators; and 2, a model with "lagged" natural disasters, where the disaster variable, measured five time periods prior to energy consumption is taken into account.

$$\ln(EnCons_{it}^{k}) = \beta_0 + \beta_1 \ln(EnCons_{i,t-1}^{k}) + \beta_2 (y_{it}) + \beta_3 d_{it}^{j} + \beta_4 \eta^{t} + \mu_i + \varepsilon_{it} \quad (1)$$

$$\ln(EnCons_{it}^{k}) = \beta_0 + \beta_1 \ln(EnCons_{i,t-1}^{k}) + \beta_2 (y_{it}) + \beta_3 d_{i,t-5}^{j} + \beta_4 \eta^{t} + \mu_i + \varepsilon_{it} \quad (2)$$

with $\mu_i \sim i.i.d(0,\sigma_{\mu_i})$, $\varepsilon_{it} \sim \text{i.i.d.}(0,\sigma_{\varepsilon})$, $E[\mu_i \varepsilon_{it}] = 0$ and where $EnCons_{it}^{k}$ is a measure of industrial energy consumption divided by the population. The subscript "k" stands for an index of total final; non-renewable; renewable; industrial; and residential energy consumption. $y_t$ is the growth rate of per capita GDP in const 2005 prices, PPP; ${d_{it}}^{j}$, is the number of occurrences of natural disasters, where the subscript $j$ stands for an index of meteorological and geological disasters. $\eta^{t}$ is a time (annual) dummy and $\mu_i$ is an idiosyncratic country specific effect.

System GMM is a method superior to fixed effects when there is an endogeneity problem in the data. The correlation between lagged dependent variables and the unobserved residual is precisely the reason why panel data is to be preferred to cross-sectional when analyzing change in the dependent variable. Cross-section estimates produce a bias, caused by the correlation between $EnCons^{k}{}_{i,t-1}$ and $\mu_i$, which disappears in samples with large time-dimension but does not disappear with time-averaging. Thus, if such a correlation exists, the true underlying structure has a dynamic nature and time-averaging cross-section techniques introduce a bias that cannot be removed by controlling for fixed-effects. Therefore, to avoid these pitfalls, we adopt the GMM methodology (Alonso-Borrego and Arellano [28]; Blundell and Bond [12]). This is a popular methodology for exploring the impact of macroeconomic conditions on energy consumption in the context of panel country data (Doytch and Narayan [29]; Sadorsky [30] and [31]). The method requires the following conditions to be met:

(i) No second order autocorrelation in the error term: $E[EnCons_{i,t-s}(\varepsilon_{it} - \varepsilon_{i,t-1})] = 0$; $E[y_{i,t-s}(\varepsilon_{it} - \varepsilon_{i,t-1})] = 0$;; $E[d_{i,t-s}^{j}(\varepsilon_{it} - \varepsilon_{i,t-1})] = 0$ for s≥2 and t=3,….T, where $y_{it}$, are the growth rate of GDP and energy consumption, which are instrumented with *GMM-style instruments* (ii) No correlation of the unobserved country-specific effect with their difference $E[(EnCons_{i,t-1} - EnCons_{i,t-2})(\mu_i + \varepsilon_{it})] = 0$; $E[(y_{i,t-1} - y_{i,t-2})(\mu_i + \varepsilon_{it})] = 0$; $E[(d_{i,t-1}^{j} - d_{i,t-2}^{j})(\mu_i + \varepsilon_{it})] = 0$. This condition allows using lagged first differences as instruments for levels. This condition is automatically checked by the by Stata when the regressions are run. An AR(2) statistic is reported for every regression equation. Due to a space constraint, we are not able report these, but we have carefully checked all AR(2) statistics to make sure that we can use lagged first differences as instruments for levels.

(ii) An additional necessary condition for the efficiency of the Blundell-Bond system GMM estimator is that, even if the unobserved country-specific effect is correlated with the regressors' levels, it is not correlated with their differences. No correlation of the unobserved country-specific effect with their difference: $E[(EnCons_{i,t-1} - EnCons_{i,t-2})(\mu_i + \varepsilon_{it})] = 0$ ; $E[(y_{i,t-1} - y_{i,t-2})(\mu_i + \varepsilon_{it})] = 0$ ;; $E[(d^j_{i,t-1} - d^j_{i,t-2})(\mu_i + \varepsilon_{it})] = 0$ . This condition also means that the deviations of the initial values of the independent variables from their long-run values are not systematically related to the country-specific effects. We instrument GDP growth rate and with GMM style instruments, which account for reverse causality with respective energy consumption variable.[1]

## 3. Data

The data set covers 80 countries and spans from 1961 to 2011. Appendix 1 displays the list of countries in the sample under four categories, based on the World Bank classification: 1, Low income countries; 2, Lower Middle Income; 3, Upper Middle Income; and 4-High Income.[2] We use an income distribution country classification, provided by the World Bank. In this study we combine categories 1 and 2 under "Low and Lower Middle Income" countries and rename them "Low Income Countries". We also rename the group of "Upper Middle Income" as "Middle I0ncome Countries". Appendix 2 presents descriptive statistics for the main variables of interest.

*Total Energy* breakdown according to International Energy Agency, documentation 2013 Edition is: *Non-renewable Energy, including:* coal, peat, crude oil and oil, natural gas; and *Renewable Energy, including*: nuclear, hydro, geothermal, solar, wind, and biofuel. Energy is measured in thousands of tones; *Industrial Energy*- used by final consumers in the industrial sector; *Residential Energy*- used by final residential consumers. Data source is International Energy Agency, World Energy Balances, Ed. 2013, extracted data set.[3]

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[1] The regressions are run on Stata 14, using the command "xtabond2" and creating instruments with the "ggmstyle" option. The GDP variable is instrumented with a two-lag-instrumental matrix.

[2] The current World Bank income brackets for "Low"; "Lower Middle"; "Upper Middle" and "High" income countries that are respectively GNI<=$1,045; $1,045 < GNI<= $4,125; $4,125<GNI<= $12,736; and GNI >$12,736, where GNI, the gross national income, is computed based on the "World Bank Atlas" method.

[3] ...........The renewable and non-renewable energy consumption are compiled from the proprietary data source "World Energy Balances", Edition 2013, availed through subscription at International Energy Agency (IEA): http://www.iea.org/t&c/termsandconditions/. For more information on data definitions, please see Appendix 2.

*Real GDP per capita* is measured in constant 2005 international dollars. We use the growth rate of r*eal GDP per capita.* The source for this variable is International Energy Agency.

Appendix 2 presents descriptive statistics for the main variables of interest. The summary in Appendix 2 show that Low Income Countries have highest share of *Residential Energy* - 47% (Top Panel "Residential Energy Consumption Share of Total") and of *Renewable Energy*- 44% (Forth Panel "Renewable Energy Consumption Share of Total". Meanwhile High Income Countries have the highest share of *Industrial Energy*- 33% (Appendix 2, Second Panel " Industrial Energy Consumption Share of Total") and of Non-*renewable Energy*- 94% (Third Panel " Non-renewable Energy Consumption Share of Total").

Natural disaster variables originate from the International Disaster Database EM-DAT [32]. Meteorological disasters include extreme temperatures and storms; climate disasters include wild fires and droughts; and geophysical disasters include landmass movements, earthquakes and volcanic activity.  In this study, we account for disaster occurrence. The summary statistics in Appendix 2 reveals that most climate disasters- 46% and meteorological disasters- 61% have been recorded in High Income countries (Panel 5 " Climate disasters" and Panel 3" Meteorological disasters). At the same time most geophysical disasters occur in Low Income Countries- 25% (Last Panel "Geophysical disasters").

## 4. Empirical Results

The full regression results from the fifteen contemporaneous models (with current meteorological, climate, and geophysical disasters) for: *Total Final Energy Consumption; Residential Energy Consumption; Industrial Energy Consumption; Non-renewable Energy Consumption; and Renewable Energy Consumption* are presented in Tables S1-S15 in the Supplementary Material. The full results from the fifteen counterpart models that refer to "lagged" natural disasters are presented in Tables S16-S30 in the supplementary material. Summary of extracted disasters regression estimates is presented in Table 1 and Table 2 for the contemporaneous and the lagged disasters respectively[4]. The results for different country groups are displayed in columns.

**<<Insert Table 1 here>>**

An overview of the Table 1, uncovering the immediate (contemporaneous) effect of *Meteorological Disasters* on *Energy Consumption* when controlling for GDP growth rate, reveals some evidence of a negative impact (Table 1; panel 1). The interesting observation about this negative impact is that the evidence points out to a specific country group being affected- the High Income Countries (Table 1, panel 1; column 4). Furthermore, the impact seems to be concentrated on *Industrial Energy Consumption* and *Non-renewable Energy Consumption* (Table 1, panel 1; column 4, rows 4 &5). The effect is strong enough to be observed at the level of *Total Final Energy Consumption* for High Income Economies[5] (Table 1, panel 1; column 4, row 1). The effect also translates to a negative impact visible for "All Countries".

The above described immediate negative effect for High Income Countries may reflect the relatively significant share in total final energy consumption that Industrial Energy use represents for these countries. The same applies for *Non-renewables*. *Non-renewable Energy* is still the same source of energy for both developed and developing countries. It is not surprising that the destruction of energy-using infrastructure associated with natural disasters has a strong impact on highly industrialized, hence high-income, countries.

Panel 2 of Table 1, describing the effects of climate disasters on energy consumption, repeats almost entirely the finding s about meteorological disaster events. The only significant results we observe are for High Income Countries and they are all negative. Adverse effects on energy consumption are found for *Industrial Energy, Renewable Energy*, as well as *Total Final Energy Consumption* (Table 1, Panel 2, column 4, rows 1, 3, and 5). This finding is consistent with the energy-driven growth hypothesis discussed in Aspergis and Tang [24], Pao, et al. [25] and Narayan and Doytch [21]. Perhaps, what is more surprising is that we do not see a more prominent effect within the groups of the developing countries (Table 1, panel 1; columns 2&3).

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[4] The full regression results for the first model specification are presented in Table 3. The full regression results for all other model specifications are presented in a Supplementary material.

[5] Please, see Appendix 2 "Descriptive Statistics of main variables".

We observe more support of the above finding when we examine Panel 3, the effect contemporaneous effect of *Geophysical Disasters*. Here we find a wider-spread negative effect of disasters on energy for in the group of High Income Countries. All types of energy: *Residential, Industrial, Non-renewable* and *Renewable Energy Consumption*, are affected (Table 1, panel 3, column 4, rows 2-5). In addition, we see a negative impact on *Non-renewable Energy* for the Middle Income Countries (Table 1, panel 3; column 3, row 4) that translates into a negative effect on *Total Final Energy Consumption* for this group (Table 1, panel 3, column 3, row 1). We explain the wider-spread of the impact of geophysical disasters on energy with their overall bigger destructiveness, in contrast to meteorological disasters, record extreme temperatures and storms, geophysical disasters, record landslides, earthquakes and volcanic eruptions, which all involve infrastructure destruction.

**<<Insert Table 2 here>>**

Table 2 records the summary of extracted regression coefficients of the "lagged" natural disasters models. Panel 1 documents the effect of 5-year lagged meteorological disasters. An exploration of this panel reveals that scarred and mixed results by country groups and type of energy. Meteorological disasters occurring five years prior appear to have a positive impact on *Non-renewable Energy* in High Income Countries, suggesting a recovery from the immediate negative effect (Table 2; panel 1; column 4, row4). High Income countries appear to be the only group recovering from meteorological disasters with time. However, the re-building is mostly in "traditional" non-renewable energy infrastructure, rather than in renewable. At the same time, meteorological disasters appear to produce a newly emerged negative effect on *Renewable Energy Consumption* in Middle Income Countries pointing out to long-term dwindling negative consequences of disasters that impede these countries on their way of transitioning to *Renewables* (Table 2; panel 1; column 3, rows 5 &1).

The lagged impact of climate disasters, described in Table 2, panel 2, has interesting implications for Low Income countries. Although the contemporaneous effect of these disasters on Low Income countries appears not to be statistically significant (Table 1, panel 2, column 2), five years after the disaster, the original destruction caused, is transformed into building more capacity into *Renewable Energy* and *Residential Energy Consumption* (Table 2, panel 2, column 2, rows 5 and 2). Since these represent almost half the energy use in the Low Income countries (please, see section 3 "Data"), building more capacity in these sources is also economically significant for the Low Income countries.

Very informative is the examination of the long-run impact of geophysical disasters, which are considered very destructive, at least in terms of infrastructure. While the immediate impact of these disasters was clearly negative and confined to the groups of Middle Income and High Income Countries (Table 1, panel 3; columns 3 and 4), the lagged effect is predominantly positive for the Low and Middle Income countries (Table 2, panel 3; columns 2 and 3). For the group of Low Income Countries, we see a positive effect on *Industrial Energy* use, indicating a surge in industrial production in the aftermath of the disaster (Table 2, panel 3; column 2, row 3). The effect is robust enough that it appears at the level of *Total Final Energy Consumption* as well (Table 2, panel 3; column 2, row 1) and is explained by a surge in non-renewable energy consumption (Table 2, panel 3; column 2, row 4). Such a positive effect on industrial production for the lowest income-level countries in the data set inevitably has long-run implications for economic growth and development of these countries.

Further, for the group of the Middle Income economies, we see a positive effect on *Residential Energy Consumption*, possibly reflecting the post-disaster reconstruction of residential dwellings and neighborhoods (Table 2, panel 3; column 3, row 2). Finally, for the group of the technologically advance, High Income economies, we see a significant long-run (five years post-disaster) effect of the disaster on *Renewable Energy Consumption.* This result suggests infrastructure upgrading during the process of re-building (Table 2, panel 3; column 4, row 5). The negative impact of lagged geophysical disasters on *Total Final Energy Consumption* that we see for the High Income countries (Table 2, panel 3; column 4, row 1) is possibly due to unobserved negative effects.

## 5. Conclusion

This study examines the impact of infrastructure-damaging natural disasters (meteorological, climate and geophysical disasters) on energy consumption differentiating by type of energy-residential vs. industrial and non-renewable vs. renewable and controlling for an impact of disasters on economic growth. We use a novel comprehensive unbalanced data set spanning fifty years (1961-2011) for up to 80 countries, which we group by level of development to reduce heterogeneity within the group. We apply an estimation method that takes into account the dynamics of the economic processes in the panel - the Blundell and Bond GMM estimator.

While it is expected for natural disasters to have negative imminent effects on energy consumption as they destroy infrastructure, including energy grids, destruct the work of oil refineries, and renewable energy-producing plants, we hypothesize that the lagged effect of a disaster (we study five year lags) could be either positive or negative. In that we are most interested with whether there is evidence of upgrading to *Renewable Energy Consumption* with the process of rebuilding. Indeed, we are able to demonstrate that for High Income economies, which are also technologically the most advanced, five years after a geophysical disaster striking, we observe that it produces a positive impact on *Renewable Energy* use. For less developed countries, we observe positive effects of geological disasters on *Industrial Energy Consumption* in the case of Low Income economies, and *Residential Energy* in the case of Middle Income countries. This overwhelmingly positive impact of lagged geophysical disasters on energy use, in spite of their immediate negative effect suggests rebuilding and some upgrading as a result of geophysical disasters. This is finding is consistent with the general Shumpeterian "creative destruction" theory evidence of which is found in Crespo Cuaresma et al. [27] and Hallegatte and Dumas [2].

Additional evidence of creative destruction is seen in the impact of climate disasters. Low Income countries, which have unusually large shares of renewable and residential energy use, enjoy further capacity building in these areas as a result of climate disasters (wildfires and droughts). The impact on renewable energy use suggests that post-disaster reconstruction provides the opportunity to decouple economic activity from the carbon footprint. The long-run relationship between disaster recovery and patterns of energy demand merits continued study.

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Table 1: Summary of regression coefficients for contemporaneous disaster effect on energy consumption by type of disaster and country level of development.

| | | (1) All Countries | (2) Low Income Countries | (3) Middle Income Countries | (4) High Income Countries |
|---|---|---|---|---|---|
| Meteorological disasters occurrence (Panel 1) | (1) Total Final Energy Consumption | **-0.00644*** | 0.00309 | 0.000793 | **-0.00841*** |
| | | **(0.00360)** | (0.00813) | (0.00838) | **(0.00497)** |
| | (2) Total Residential Energy Consumption | 0.00111 | 0.00428 | -0.00849 | 0.00548 |
| | | (0.00471) | (0.00950) | (0.0151) | (0.00543) |
| | (3) Total Industrial Energy Consumption | -0.00834 | 0.00571 | 0.0142 | **-0.0125**** |
| | | (0.00519) | (0.0128) | (0.0184) | **(0.00568)** |
| | (4) Total Non-renewable Energy Consumption | -0.00470 | -0.00404 | -0.00109 | **-0.00658*** |
| | | (0.00453) | (0.00712) | (0.00773) | **(0.00376)** |
| | (5) Total Renewable Energy Consumption | 0.00363 | 0.0103 | -0.0158 | 0.00786 |
| | | (0.00947) | (0.00830) | (0.0167) | (0.0193) |
| Climate disasters occurrence (Panel 2) | (1) Total Final Energy Consumption | 0.00124 | -0.0159 | 0.0130 | **-0.00362*** |
| | | (0.00342) | (0.0253) | (0.00944) | **(0.00201)** |
| | (2) Total residential energy consumption | 0.0109 | -0.0258 | 0.0245 | -0.00714 |
| | | (0.0117) | (0.0332) | (0.0240) | (0.00548) |
| | (3) Total Industrial Energy Consumption | -0.00426 | -0.0538 | 0.0305 | **-0.013***** |
| | | (0.00735) | (0.0569) | (0.0243) | **(0.00276)** |
| | (4) Total Non-renewable Energy Consumption | 0.00439 | -0.0180 | 0.00877 | -0.00324 |
| | | (0.00595) | (0.0283) | (0.0112) | (0.00241) |
| | (5) Total Renewable Energy Consumption | 0.00508 | -0.0456 | 0.0124 | **-0.0192*** |
| | | (0.0185) | (0.0477) | (0.0393) | **(0.0105)** |

| | | | | | |
|---|---|---|---|---|---|
| Geophysical<br>disasters<br>occurrence<br>(Panel 3) | (1) Total Final Energy Consumption | -0.00233 | 0.00474 | **-0.0215**** | -0.0115 |
| | | (0.00493) | (0.00722) | **(0.00867)** | (0.00703) |
| | (2) Total residential energy consumption | -0.000514 | 0.00982 | 0.00593 | **-0.0166*** |
| | | (0.00837) | (0.00617) | (0.0314) | **(0.00992)** |
| | (3) Total Industrial Energy Consumption | -0.0154 | 0.00202 | -0.00581 | **-0.0356**** |
| | | (0.0136) | (0.0222) | (0.0182) | **(0.0142)** |
| | (4) Total Non-renewable Energy Consum. | -0.00443 | 0.00492 | **-0.021***** | **-0.0104**** |
| | | (0.00600) | (0.00925) | **(0.00758)** | **(0.00520)** |
| | (5) Total Renewable Energy Consumption | -0.0138 | -0.00305 | -0.00116 | **-0.105*** |
| | | (0.0201) | (0.00638) | (0.0501) | **(0.0631)** |

Table 2: Summary of regression coefficients for lagged disaster effect on energy consumption by type of disaster and country level of development.

| | | (1) | (2) | (3) | (4) |
|---|---|---|---|---|---|
| | | All Countries | Low Income Countries | Middle Income Countries | High Income Countries |
| Meteorological disasters occurrence (Panel 1) | (1) Total Final Energy Consumption | -0.00178 | 0.000960 | -0.0202* | 0.00421 |
| | | (0.00272) | (0.00318) | (0.0116) | (0.00375) |
| | (2) Total Residential Energy Consumption | -0.0081** | -0.00608 | -0.00991 | -0.00596 |
| | | (0.00386) | (0.00685) | (0.0292) | (0.00374) |
| | (3) Total Industrial Energy Consumption | -0.00437 | -0.00150 | -0.0520 | 0.00489 |
| | | (0.00520) | (0.00859) | (0.0349) | (0.00618) |
| | (4) Total Non-renewable Energy Consumption | -0.000920 | -0.00464 | -0.0206 | 0.00587** |
| | | (0.00308) | (0.00429) | (0.0129) | (0.00299) |
| | (5) Total Renewable Energy Consumption | -0.0108 | -0.00483 | -0.0838** | -0.0135 |
| | | (0.00811) | (0.00873) | (0.0397) | (0.0155) |
| Climate disasters occurrence (Panel 2) | (1) Total Final Energy Consumption | 0.00271 | 0.0184 | 0.00682 | 0.000376 |
| | | (0.00374) | (0.0114) | (0.0182) | (0.00189) |
| | (2) Total residential energy consumption | 0.0101 | 0.0450** | -7.58e-06 | -0.00022 |
| | | (0.00809) | (0.0218) | (0.0253) | (0.00710) |
| | (3) Total Industrial Energy Consumption | 0.00282 | 0.0181 | 0.0116 | -0.00122 |
| | | (0.00939) | (0.0246) | (0.0299) | (0.00444) |
| | (4) Total Non-renewable Energy Consumption | 0.000945 | 0.0204 | 0.00584 | 0.000105 |
| | | (0.00412) | (0.0167) | (0.0186) | (0.00200) |
| | (5) Total Renewable Energy Consumption | -0.0190 | 0.0403** | 0.0465 | -0.0280 |
| | | (0.0204) | (0.0194) | (0.0484) | (0.0223) |

| | | | | | |
|---|---|---|---|---|---|
| Geophysical disasters occurrence (Panel 3) | (1) Total Final Energy Consumption | 0.00772 | **0.0215***** | 0.00686 | **-0.0180**** |
| | | (0.0107) | **(0.00533)** | (0.00980) | **(0.00806)** |
| | (2) Total residential energy consumption | 0.0124 | 0.00661 | **0.0355***** | -0.000252 |
| | | (0.0123) | (0.00527) | **(0.00904)** | (0.00532) |
| | (3) Total Industrial Energy Consumption | 0.0143 | **0.0421*** | -0.0147 | -0.0229 |
| | | (0.0374) | **(0.0223)** | (0.0178) | (0.0177) |
| | (4) Total Non-renewable Energy Consumption | .006679 | **0.0350***** | .0035076 | **-.01878**** |
| | | (0.01158) | **(0.00716)** | (0.012853) | **(0.008071)** |
| | (5) Total Renewable Energy Consumption | 0.0386 | 0.00911 | 0.0311 | **0.0740**** |
| | | (0.0303) | (0.0123) | (0.0522) | **(0.0320)** |

Table 3: Meteorological Disasters impact on Total Energy Consumption

|  | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| VARIABLES | All Countries | Low & Lower Middle Income Countries | Upper Middle Income Countries | High Income Countries |
| Lagged LN Total | 1.001*** | 0.974*** | 0.984*** | 0.982*** |
| En. Cons. per capita | (0.00551) | (0.0143) | (0.0208) | (0.00618) |
| Growth GDP | 0.596*** | 0.184** | 0.670*** | 0.180 |
| 05USD,ppp, per cap | (0.142) | (0.0724) | (0.154) | (0.193) |
| Ln (meterological | **-0.00644*** | 0.00309 | 0.000793 | **-0.00841*** |
| dis. occurrence) | **(0.00360)** | (0.00813) | (0.00838) | **(0.00497)** |
| Constant | -0.00703 | **-0.198*** | -0.110 | **-0.101**** |
|  | (0.0388) | **(0.112)** | (0.133) | **(0.0459)** |
| Observations | 926 | 343 | 159 | 424 |
| Number of countries | 80 | 30 | 26 | 30 |
| AR(2) | 0.833 | 0.398 | 0.340 | 0.718 |
| Sargan stat. | 0.985 | 0.993 | 0.000 | 0.972 |

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1