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Abstract

New fears about escalating fuel prices and accumulating inflation are raising concerns about the possible dimming of near-term prospects for world economic growth. The role of energy prices in shaping economic growth relates not only to geopolitical risks or environmental taxes but also to a range of strategies that place moratoria on primary energy sources like nuclear, coal, petroleum, and natural gas. Applying a new data set for country-level energy prices since 1960, this study evaluates the effects of energy prices on economic growth in 18 OECD countries by controlling for other important macroeconomic conditions that shape economic activity. Mean-group estimates that control for cross-country correlations are used to emphasize average responses across nations. Averaged across all nations, results suggest that a 10 percent increase in energy prices dampened economic growth by about 0.15 percent. Moreover, some evidence exists that this response may be larger for more energy-intensive economies.

Key words: OECD economic growth; energy prices; cross-country panel analysis

JEL Codes: C23, C33, O47, Q43, Q54

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1. Introduction

The Russian invasion of Ukraine in February 2022 added new fears about further escalating fuel prices, accumulating inflation, and the possible dimming of near-term prospects for world economic growth (International Monetary Fund, 2022). Countries were already searching for ways to steer nascent recoveries from the coronavirus pandemic in the midst of supply-chain bottlenecks and emerging inflation. The underlying inflationary and growth conditions brought back memories of previous decades of the 1970s when middle eastern crude oil supplies were disrupted and the world economy stagnated. One of the major differences with these new conditions is that the invasion and the sanctions on Russia imposed by the West threaten not only oil but also other fossil fuels like natural gas and coal. Although how future economic conditions will respond to these events is highly unknown at this time, these developments have rekindled a very strong interest in how the prices for all energy forms influence economic growth, particularly during inflationary periods.

These events are transpiring at a time when economies are transitioning from fossil fuels to cleaner energy options that emit much less carbon, methane and other greenhouse gases. When these options are more expensive than traditional sources, firms and households are less likely to shift towards them in the absence of new abatement policies. Under these conditions, the relative benefits of these policies involve a tradeoff between the social benefits from a cleaner environment and any economic dislocation caused by the additional private costs. Lower future GDP losses from an imposed strategy favor more aggressive abatement policies, *ceteris paribus*; higher future GDP losses work against more aggressive abatement policies.

Assessments of this tradeoff based upon large-scale simulation or general equilibrium models are widely available and provide a useful structure for thinking about what is known and unknown about these strategies (Weyant, 2014). Weyant and Kriegler (2014) provide a useful summary of some the major efforts to conduct structural model comparisons of these systems. A potential limitation of these efforts is that there is often limited empirical information on a number of factors, including the economic impacts of increasingly higher energy costs over long periods.

Most available empirical studies of these effects are based upon the economic response to oil prices over the business cycle. It is not intuitive or obvious that these estimates apply to other energy sources over a lengthy transition period. Petroleum is used primarily although not exclusively in the transportation sector. Broader transitions across the entire energy system will influence decisions and economic adjustments for other fuels in other sectors and potentially can have different economic effects.

Several efforts have estimated the economic response to environmental taxes, as will be discussed in the next section. Although economists favor environmental taxes as the least-cost strategy, this approach is only one abatement option that many country leaders are reluctant to choose. Instead, they often consider mandates that restrict the use of certain types of fuels that are considered dirty. Recently, there have been early retirement of nuclear plants in Germany, Italy, Belgium, and Switzerland without a clear strategy for providing for the rapid growth in power demand. Moratoria on future natural gas use in homes in various Massachusetts and California localities in favor of all electric homes may be beneficial in the long term but will similarly restrict the energy system from adapting to changed technology or market conditions during the transition. Commitments to phase out coal by 2030 have already been adopted by the new German coalition government. These policies tend to raise energy fuel costs without imposing a fee and collecting revenues that can be redistributed back into the economy.

For this reason, there should be strong interest in the role of energy fuel prices in shaping economic growth over the transition period.

The main contribution of this study will be to evaluate how energy fuel prices shape economic growth over multiple decades by including a number of key macroeconomic indicators as control variables that also influence growth. The empirical mean-group estimates for 18 OECD nations over the 1960-2016 period also incorporate a correction for correlations between the economies caused by global shocks influencing all nations. Emphasis is placed upon identifying a representative result for the included 18 OECD countries rather than for an in-depth evaluation of each country's experience. It applies a new data set for country-level energy prices that are available back to 1960. The results confirm a significant inverse relationship between economic growth and energy fuel price changes that are robust to several alternative estimating approaches. Moreover, there exists some limited support for this inverse relationship to be stronger for energy-intensive economies.

The next section reviews several themes from the previous literature that are directly relevant to our own interests. Section 3 follows with a discussion of the estimation approach and a description of the data and their properties. Key results from the panel analysis are discussed in section 4. Several insights from the individual panel results are considered in section 5, before summarizing the findings in section 6.

2. Past Studies

The analysis draws from a rich set of analytical studies for evaluating the conditions shaping economic growth. This section focuses on the several strands that relate most closely to our chosen empirical methodology: the use of an annual mean-group specification applied to country panel data for 1960-2016.

Barro (1991) and Mankiw et al. (1992) pioneered an extensive line of research to understand the determinants of long-run economic growth and whether there is evidence for convergence in per-capita GDP levels between nations. Studies abstract from business-cycle fluctuations by explaining economic growth over multiple years, often but not exclusively a ten-year horizon like a decade. Initial studies used cross-section data from multiple countries for the same period. As longer series became available, analysts applied panel data techniques incorporating several sets of periods. Panel data techniques have several advantages over individual time-series econometrics for evaluating economic growth (Temple, 1999), including that they raise the statistical power and inference of the model by allowing more observations.

Equations usually included per-capita real GDP levels at the beginning of each horizon that allowed an examination of the conditional convergence properties. Economies with higher incomes grow slower than their less wealthy counterparts because they experience diminishing returns by having higher initial levels of capital per worker and hence lower returns to that factor, holding constant a number of control and environmental conditions. Results about convergence vary depending upon which countries are included and over what time period, but it has been consistently shown that the economy's original position (its initial GDP level) is an important determinant of future economic growth. Studies have introduced multiple control variables as levels, either in the beginning year of each horizon or as an average for all years over the period.

A subset of these studies has focused on the relationship between inflation and economic growth that may influence the role of energy prices under certain conditions. Kremer et al. (2013) examined the long-term ramifications for economic growth in developed and developing countries over a five-year horizon from the country's inflation rate. In addition to the initial real GDP level and the population growth rate, they included several control variables: the consumer price index, gross investment's share of GDP, and total export and import trade as a percentage of GDP. For the mature

OECD economies over the 1950-2004 horizon, they found that long-term economic growth was unaffected until inflation rates reached 2 percent per year. Using data from more than 100 countries over the 1960-1990 horizon, Barro (2013) also discovered slower long-run economic growth for countries with high inflation rates. He included about 14 control variables representing initial real GDP levels, human capital indicators, government consumption's share of GDP, investment's share of GDP, terms of trade, and various institutional conditions such as rule of law and democratization.

Beginning in the early 1990s, environmental taxes and affiliated tax reforms began to surface in a number of OECD countries. Theoretical studies have dominated the literature on this topic and have resulted in a range of possible outcomes that can lead to either a positive or negative impact on economic growth. Although these taxes can directly raise production costs within the economy, they can stimulate future economic growth if they allow policies that reduce the rates of distortionary taxes on labor and capital (Goulder, 1995). In addition, by improving the quality of the environment, these taxes can reduce the need for spending on healthcare services and other expenses required to offset the effects of pollution and shift resources towards more productive uses like education (Oueslati, 2015). A number of studies based upon large-scale economic simulation or general equilibrium models have also explored how environmental taxes can be reformed by reducing distortionary taxes on other inputs (McFarland et al., 2018), but econometric studies on environmental taxes have been relatively limited.

Two exceptions are worth noting. Applying Granger causality tests to panel data, Abdullah and Morley (2014) suggest that faster growing economies tend to have larger environmental tax revenues, but they find little evidence of the reverse where environmental tax revenues curtail economic growth within Europe or the OECD over the relatively short 1995-2006 period of slightly more than a single decade. More recently, Hassan et al. (2020) used panel analysis to evaluate the annual experiences of 31 OECD countries over the 1994-2013 period. They conclude that higher revenues from environmental taxes are associated with lower economic growth rates, but they can promote growth in those economies with a higher initial level of GDP per capita.

These studies provide important contributions to understanding the role of environmental taxes, but it is important to understand some key limitations. The empirical research is based entirely or primarily upon using OECD data on total tax revenue or its share of the economy's total GDP as a proxy for environmental tax *rates*. This data is available only from the mid-1990s when environmental taxes finally became an important policy topic. Moreover, differences in how much tax revenues increase will incorporate not only the increase in the tax *rate* (the critical conditioning variable) but also how economies respond to any given tax rate increase. Greater response in pollution abatement to environmental taxes will reduce the increase in tax revenues and may even reduce total revenues when the response is very high (i.e., when the elasticity exceeds unity). It is also important to acknowledge that this research limits itself to a single policy strategy of using environmental taxes when the policy community may be interested in the broader issue of how conditions leading to higher energy prices influence economic growth.

In addition to these long-run economic growth studies, an equally expansive literature exists for understanding the role of crude oil prices in shaping economic performance over the business cycle. Studies abstract from long-run conditions by explaining quarterly economic performance (real GDP) as a function of its own changes as well as those for other economic factors including oil prices, often over the previous four quarters. They often focus upon the United States, although some studies analyze the OECD countries (Jimenez-Rodrıguez and Sanchez, 2005; Kilian, 2008; Blanchard and Gali, 2010; and Gómez-Loscos et a., 2012). Herrera et al. (2019) provide a recent review of key conclusions from the USA studies and the important insights drawn from multiple structural vector autoregressive (SVAR) equations on high-frequency data (often quarterly). An evaluation by Moghaddam and Lloyd-Ellis (2022) on the economic response of Canadian provinces to crude oil prices represents an exception to this shorter-run focus. Their work is related in spirit to what we explore below in the current analysis with multiple countries but their emphasis on crude oil costs alone differs from our broader interest on the role of all fuel prices.

The shorter-run crude oil studies find an inverse relationship between real GDP and supply-side shocks in crude oil prices. Several explanations have been offered to support this empirical result. Direct effects of substituting away from more expensive energy via neoclassical production function are likely to explain only small part of the energy price effect. Among the indirect effects, energy price shocks have been likened to an adverse technology shock that leaves the existing capital stock physically in place but dampens industrial capacity utilization rates and thereby reduces the service flow from capital (Berndt and Wood, 1976; Finn, 2000). Aggregate economic output declines temporarily as labor and capital adjust and shift between sectors imposing adjustment costs (Hamilton 1988, Davis and Haltiwanger, 2001). The indirect effect through aggregate demand may operate if energy prices contribute to higher consumer prices and a tightening real monetary position (as emphasized by Blanchard and Gali, 2010, p. 375, and Nordhaus, 2007, p. 223), particularly if governments do not offset these effects due to either public inertia or fears about exacerbating inflationary pressures. Other researchers emphasize the uncertainty for investment caused by large and unexpected energy price fluctuations (Hamilton (1996, 2003), Ferderer (1996), and Balke et al. (2002)) and declines in output and real wages due to implicit collusion between oligopolist firms within the energy-using economy that are larger than under pure competition (Rotemberg and Woodford, 1996).

This research also emphasizes that the effects associated with recent oil price fluctuations appear modest relative to the earlier oil price shocks that dominated the 1970s (Blanchard and Gali, 2010, Nordhaus, 2007, Gronwald, 2008). There appear to be two separate but not mutually exclusive reasons for the more modest effects in the later period. First, oil-supply shocks dominated the earlier period, while oil-demand shocks played an important role in the later period. Oil-supply shocks cause larger GDP reductions than do oil-demand shocks (Kilian, 2009). Oil supply disruptions result in higher oil prices and reduced economic activity. Oil demand shocks originating from domestic economy-wide productivity gains result in higher oil prices and increased economic activity. Similar oil demand shocks from foreign productivity gains can boost oil prices and have neutral effects on domestic economic output. In such cases, oil price increases are likely to yield smaller if any economic losses.

Second, underlying economic conditions within the OECD were quite different during the stagflationary 1970s than in later years. Many nations adopted more effective and stable rules governing the money supply that tamed inflation rates after the 1970s. As a result, monetary policy in the later period could be more effective in offsetting oil-price fluctuations without accelerating inflationary fears.

Although important for central banks, this research must limit its scope to a relatively small number of factors because four lagged values are often used for each variable in order to capture the full impact of the oil price shock. The approach is not well suited for incorporating even the most major drivers of economic growth found in other studies discussed initially in this section. In addition, this approach has not been extended to other energy sources like natural gas, coal and electricity that may be shaped more by local conditions including limited access to electric power grids or natural gas infrastructure than by global trends. Nevertheless, several key findings from these studies influence the research design explained below by emphasizing the need for incorporating the possible endogeneity of energy fuel prices and for separating the sample between the pre- and post-Great-Moderation period, using the 1982 benchmark suggested by McConnell and Quiros (2002).

3. Empirical Approach and Data Properties

A key contribution of the current study will be to use annual panel data techniques to evaluate responses across multiple country experiences. Energy is only one contributing factor, and it may not play a dominant role in influencing economic growth. For this reason, we adopt an approach that allows the consideration of other variables that have been important in previous studies of economic growth. The framework, however, will focus on annual economic performance rather than longer-run economic growth patterns. In contrast to the studies on higher frequency data, it will also expand consideration to all major energy sources rather than crude oil alone.

This analysis focuses on the annual effect of energy prices on economic growth rather than its influence of the business cycles within 18 OECD nations.[1] The approach emphasizes panel data specifications that allow for cross-country heterogeneity in the response to each variable and that adjust for cross-section dependence between the errors by country. The data are balanced over the 1960-2016 period for 16 countries but cover the 1962-2016 horizon for Germany and the 1972-2016 period for Australia. The study conducts this long panel evaluation by taking advantage of a recent set of international energy price series that have been extended back through 1960 for many countries. These country-level prices are a real price index for all fuel and power across all sectors in constant (2010) US dollars. This energy price data set also includes a number of countries outside of the OECD, but these additional price series were generally shorter. They were seldom extended back before 1978 and in the few cases where they did, they began in 1973. Although the energy price data provides a rich coverage of many countries over long time periods, they are annual rather than quarterly or monthly series. With lower frequency data, it is more difficult to identify structural restrictions that are economically plausible as in the approach used by the literature on short-term oil price shocks that was discussed in section 2 above.

3.1 Specification Issues

[1] These countries included Australia, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom and United States. A full energy price series covering all years was also available for Greece, but this country was not covered by the macro data base. Missing energy prices included Germany (1960-61) and Australia (1960-71).

Particular emphasis is given to the relationship between real GDP (*y*), the consumer price index (*p*), and energy fuel prices (*f*). Current energy prices can influence current GDP directly as well as indirectly through its effect on the current CPI as described in the literature review in Section 2. Dropping the constant and the IID disturbance term for ease of presentation at this stage, these three variables can be represented by these equations:

$$\Delta p_{it} = \sum_{j=1}^{N} \beta_{ij1}\, \Delta p_{i,t-j} + \sum_{j=0}^{N} \beta_{ij2}\, \Delta f_{i,t-j} \tag{1}$$

$$\Delta y_{it} = \sum_{j=1}^{M} \gamma_{ij1}\, \Delta y_{i,t-j} + \sum_{j=0}^{N} \gamma_{ij2}\, \Delta p_{i,t-j} + \sum_{j=0}^{N\prime} \gamma_{ij3}\, \Delta f_{i,t-j} \tag{2}$$

where Greek letters are estimated coefficients, the subscripts *i* and *t* denote country and year, respectively, the subscript *j* represents the lag, and the Δ symbol indicates the change operator. CPI changes are based upon lagged CPI changes[2] and current and lagged values for energy fuel price changes. Attention to the growth equation follows if one substitutes the aggregate price deviation for the current year (Δp_{it} when lag $j = 0$) into the GDP change:

$$\Delta y_{it} = \sum_{j=1}^{M} \gamma_{ij1}\, \Delta y_{i,t-j} + \sum_{j=1}^{N} \pi_{ij1}\, \Delta p_{i,t-j} + \sum_{j=0}^{N\prime} \varphi_{ij1}\, \Delta f_{i,t-j} \tag{3}$$

where $\pi_{ij1} = \gamma_{ij2}\beta_{ij1}$ and $\varphi_{ij1} = \gamma_{ij2}\beta_{ij2}+\gamma_{ij3}$. When consumer prices play no role in the growth process ($\gamma_{ij2} = 0$), $\pi_{ij1} = 0$ and the role of energy prices reduces to its direct effect where $\varphi_{ij1} = \gamma_{ij3}$. Whether this assumption is warranted will be tested by including the π_{ij1} parameter in the estimates below.

There may be a reverse causation where economic growth (Δy_{it}) influences energy fuel prices (Δf_{it}) because the lag structure on the latter variable includes its current value. To circumvent this potential problem, the trends in energy fuel prices within each country are instrumented by a set of international energy market variables that drive the price movements within each country.

[2] Lagged values are not ideal for explaining current inflation, but Barro (2013) describes the problems with other possible series.

$$\Delta f_{it} = \sum_{j=1}^{N} \alpha_{ij1}\, \Delta f_{i,t-j} + \sum_{j=1}^{N} \alpha_{ij2}\, \Delta z_{i,t-j} \tag{4}$$

The z-vector includes the change in world GDP (which includes the important role played by growth outside the OECD), government-controlled middle eastern oil supplies, the interruption of international supplies caused by the Iranian revolution in 1979, and geological conditions shaping US resources as represented by the share of world supplies originating from the United States. Adelman (1980) makes a strong argument for why the middle eastern oil producers should be viewed as a clumsy cartel meeting multiple economic and political goals rather than as a profit-maximizing agent trying to optimize its net profits only. This variable controls for the rapid decline in world oil production increases in the early 1970s as well as its rapid expansion in the mid-1980s. Similarly, the US share of world supplies is most likely exogenous because it reflects the long-run geological depletion of traditional U.S. sources early in the period and the sudden surprise of accessible new shale formations for oil and gas later in the period. Much of the success of the new shale formations was due to intensive government research and development in the 1970s followed by gradual transformations in how oil and gas drilling evolved in the years leading to its major appearance around 2007. These factors explain why this advanced oil-production technology was concentrated in the United States and was not quickly adopted in other regions that also experienced higher prices.

These relationships operate within a broader economic system where other variables may also influence economic growth. Based upon past studies exploring the long-run growth patterns, the study included several other key variables whose exclusion might bias the estimated responses to energy fuel price changes. The effects of these control variables are not explored in greater depth below given the focus of the current analysis, but efforts are made to check that these factors operate in the expected direction and whether they are statistically significant.

These factors include gross investment's share of the total economy, government's share of total GDP, and the openness of the economy to international trade as measured by the sum of exports and imports relative to GDP. When investment expands relative to real GDP, past studies have shown more rapid economic growth. When government expenditures expand relative to GDP, more resources are channeled to slower-growing sectors financed by public expenditures and economic growth should be less rapid. Economic growth has also been faster in economies with a greater openness to international trade that allows them to purchase less-expensive goods from abroad and sell products where they have a comparative advantage to foreign economies.

Adding these control variables raises the possibilities that some factors may operate over the long term as well as have immediate impact. Ideally, one would like to estimate a functional form that allowed the data to determine both short-run and long-run effects if they exist. One such specification that is commonly used for these purposes is the unrestricted error correction model:

$$\Delta y_{it} = \sum_{j=1}^{M} \gamma_{ij1}\, \Delta y_{i,t-j} + \sum_{j=1}^{N} \pi_{ij1}\, \Delta p_{i,t-j} + \sum_{j=0}^{N\prime} \varphi_{ij1}\, \Delta f_{i,t-j} + \sum_{j=0}^{N\prime\prime} \lambda_{ij1}\, \Delta X_{i,t-j} \quad (5)$$

$$+\lambda_{i1} y_{i,t-1} + \lambda_{i2} p_{i,t-1} + \lambda_{i3} f_{i,t-1} + \lambda_{i4} X_{i,t-1} + \epsilon_{it}$$

where *X* is a vector of the control variables discussed immediately above, the λ coefficients represent long-run parameters, the subscripts and other Greek letters have been described above, and ε_{it} indicates the independent and identically distributed error terms.

If the data-generating model or process consists of heterogeneous slopes that vary between countries as indicated above, panel-data estimates that restrict the same responses for all countries yield inconsistent and biased results. Applying the delta test (Pesaran and Yamagata, 2008) to Equation (5) rejects homogeneous slopes across countries at the 1% level with a value of 16.39 for all variables, with a value of 7.38 for all first-difference coefficients, and with a value of 24.59 for all lagged coefficients. These tests use the heteroskedasticity- and autocorrelation-consistent (HAC) robust standard errors employing a Bartlett kernel following Blomquist and Westerlund (2013).

Heterogeneous responses are allowed by estimating this common framework for each country in the sample. Country-specific responses can vary dramatically from each other and sometimes produce unrealistic estimates. For this reason, the analysis uses the Mean Group estimator (MG) for panel data which averages the individual country responses across nations. This approach is particularly attractive for identifying a representative result for the included countries rather than for an in-depth evaluation of each country's experience. It possesses the additional advantage of applying the same conceptual framework to each country, thereby minimizing country variations caused by different model specifications for the key variables.

Another advantage of this approach is that it can easily incorporate common factors that influence all countries in the sample. OECD economies share a common experience through international trade, coordinated government policies, similar economic structures, and vulnerabilities to international food, raw material, and energy price shocks. The MG estimator can be expanded to include time series that measure the cross-sectional average of each variable in the country equations (Chudik and Pesaran, 2015). Applying this approach, the Common Correlated Effects Mean Group estimator (CCEMG), provides consistent estimates that would not be available by ignoring these adjustments.

3.2 Data Sources and Properties

All data except for energy prices have been extracted from the Jordà-Schularick-Taylor (JST) Macrohistory Database[3] covering 18 advanced economies. For these same countries, we use the relevant energy price data constructed by Liddle and Huntington (2020a) in their evaluation of world

[3] Jordà, O., et al. (2017). This macroeconomic data set is available at http://www.macrohistory.net/data/ (accessed 2/7/2022).

energy demand and updated in an investigation of energy technology leapfrogging by the same authors (Liddle and Huntington, 2021).[4] These prices (ENERGY) are for aggregate energy use for both direct fuel and power applications. They cover the major fuels - petroleum, natural gas, coal and electric power - in the residential, industrial, and transportation sectors and hence will be referred to as energy fuel prices below to emphasize that any renewable energy costs, although small relative to the total, are excluded. Although country energy fuel prices and international crude oil prices move upward and downward in tandem throughout the period, the cross-country variation in the trends for energy fuel prices are substantial. (See the discussion in Liddle and Huntington, 2020a, and their Figure 1).

The energy fuel prices are based primarily upon the International Energy Agency's (IEA) real index for industry and households, sourced from their Indices of Energy Prices by Sector. For years prior to 1978 and for 15 countries, these series have been spliced with unpublished estimates from Baade (1981) that have been used in previous published articles (Adeyemi and Hunt, 2007, 2014; Griffin and Schuman, 2005; and Huntington, 2006). For an additional three countries (Australia, Finland, and Germany), the OECD series CPI-Energy and CPI-All Items are used to extend prices back from 1978. Further information about the series is available in Liddle and Huntington (2020a).

In addition to gross domestic product (GDP), the estimates also include key macroeconomic control variables often used in long-term growth studies. They include the consumer price index (CPI) and the relative importance of open economies indicated by the sum of total exports and imports (OpenTrade), investment (Invest) and federal government expenditures (GovExp) in the total economy. These last three variables are expressed as ratios relative to the economy's total GDP and are not converted to natural logarithms. More open economies (OpenTrade) and larger investment shares

[4] Liddle and Huntington (2020b) provide the energy fuel price data, which are available at: https://data.mendeley.com/datasets/3nmbz2jyd2/1 (accessed 2/7/2022).

(Invest) stimulate economic growth, while greater federal government expenditure shares (GovExp) decrease the growth.

Long historical databases provide a unique opportunity to understand evolution patterns covering different economic and energy conditions. A downside of using such sources is that they are updated only occasionally and may not cover the most recent years. In our case, the joint data covering both the macroeconomy and energy sectors allow an evaluation through the end of 2016. In more recent years, Brent crude oil prices have risen from $44 per barrel in 2016 to $117 per barrel in March 2022.[5] Much of the pre-2020 increase in energy prices was due to faster economic growth, which ranged between 1.74% and 2.54% within the OECD member countries over the 2016-2019 period.[6] Our approach using instrumental variables for energy prices to focus upon supply-side shocks should minimize the effect of these years on our estimates if data availability issues had not prevented them from being included in the sample. Since 2020, the pandemic followed by the Russian invasion of Ukraine ushered in a new set of conditions whose long-run effects are unknown at this point and will require further research. Thus, the major contribution of this analysis is to set a benchmark for understanding the historical role of energy prices in economic growth that may serve useful for future research to identify what is similar and what differs with the new post-2019 conditions.

Table 1 demonstrates that the sample offers a wide range of country experiences by reporting means and the within-country standard deviations, maximums and minimums for each variable. Measuring the standard deviation relative to the mean value, the coefficient of variation shows that the real GDP level and the real energy price level vary considerably less than consumer prices and the other variable levels.

Table 1

[5] US Energy Information Administration, https://www.eia.gov/petroleum/data.php (Accessed 4/20/2022).
[6] World Bank, Open Data, https://data.worldbank.org/ (Accessed 4/20/2022).

Applying ordinary least squares (OLS) regressions on panel or time-series variables that are not stationary can produce unreliable R-squared and t-statistics and raises a serious risk of the estimated relationships being spurious unless these non-stationary variables are cointegrated (Kao 1999; Beck 2008). The variables appear to be nonstationary in levels but stationary in differences as a general rule whether or not a trend is included. Table 2 displays these results, which are based upon the Pesaran (2007) t-test for unit roots in heterogenous panels with cross-section dependence based upon the correlation coefficients between the time-series for each panel member. The null hypothesis is that all panels have a unit root. Rejection means that the variable's level (or first difference) is stationary for at least one or more panels. Table 2 summarizes these unit root tests over the full 1962-2016 sample for: (i) a constant but no trends in levels, (ii) no trend in first differences, and (iii) a trend as well as a constant in levels. The test drops the trend when considering unit roots in the variable's change indicated by the first-difference operator (D.) in the table. Open Trade is an exception to the pattern described above. It appears stationary in levels unless the test includes a trend in the levels specification.

Table 2

The most critical finding from Table 2 is that all variables are stationary in either levels or first differences, i.e., the variables are I(0) or I(1). When all variables are stationary at least in first differences if not levels, the Pesaran et al. (2001) bounds test for cointegration will be useful for determining whether to use an unrestricted error-correction model or a simple first-difference equation. Unlike other cointegration tests, their bounds approach is less restrictive about assumptions concerning the stationarity of all the variables, because it does not require that one be certain that the variables are I(1) in levels.

Cointegration in this test depends upon whether an F-test on the lagged variables exceeds a critical value for the upper-bound case when all variables are I(1). In this approach an unrestricted errorcorrections model (ECM) as represented by Equation (5) is estimated for each individual panel. Energy fuel prices are segmented into two components for before and after 1982, as described below in the results section. An AIC test determines the optimal lagged terms for the first differences with a maximum three lags imposed. Both the Breusch-Godfrey test and the Durbin alternative test are used to confirm that one cannot reject the null hypothesis of a lack of autocorrelation. An F-test was conducted on the variables in levels which were a mix of I(0) and I(1) variables rather than on all I(0) variables. It is applied to determine whether the combination of all lagged levels in the ARDL can jointly be rejected using the criteria values provided by Kripfganz and Schneider (2020) for the upper bound for I(1) variables. The null hypothesis is that cointegration fails to exist in any of the individual country panels. These critical values were exceeded in 14 of the 18 panels, suggesting that the error correction specification is suitable and that the panel equation should include the lagged levels. The average F-statistic across all panels of 7.24 was substantially greater than the critical value for I(1) variables at the 5% level, which fluctuated between 5.34 and 5.90 depending upon the final equation selected by the AIC for each panel.

An important advantage of using relatively long panel series is that it reduces possible bias accruing from a dynamic specification. Having 57 annual observations for most panels and 39 annual observations for three panels imply a small dynamic bias, usually on the order of 1/T (Nickell 1981). In unbalanced panels (like ours), the bias becomes less of a problem when the average group (cross-section) size increases and is not determined solely by the shortest series (Bruno, 2005). Adjusting for bias is not recommended unless there are less than 20 observations per panel (Beck and Katz, 2009) or 30 observations per panel (Judson and Owen, 1999).

4. Results

The standard method for reporting MG coefficients is to use unweighted means of the individual panel results. This approach may not be appropriate if the sample contains some large outliers that would bias the results. To ascertain this potential bias, equation (5) was estimated by applying both unweighted means and their robust-outlier counterparts. By eliminating insignificant lagged differences, a more parsimonious equation for testing coefficient significance was possible of the following form:

$$\Delta y_{it} = \pi_i \Delta p_{i,t-1} + \varphi_i \Delta f_{i,t} + \lambda_i \Delta X_{i,t} + \lambda_{i1} y_{i,t-1} + \lambda_{i2} p_{i,t-1} + \lambda_{i3} f_{i,t-1} + \lambda_{i4} X_{i,t-1} + \epsilon_{it} \quad (6)$$

where the variables and coefficients are the same as those for equation (5). Both lagged government expenditures and lagged energy fuel prices were insignificant so their λ coefficients were dropped in this and all remaining equations. Table 3 shows that the unweighted and robust-outlier coefficients are quite similar and that their statistical significance are the same. A χ2-statistic of 11.62 in the Hausman test fails to reject that the differences in coefficients are not systematic.

Table 3

Based upon previous studies discussed in the literature review, the revised equation (6) was then estimated to explore the response of economic growth to energy fuel prices and to the lagged consumer price index. These estimates use the instrumental variables discussed under equation (5) to adjust for any possibility that energy fuel prices are endogenous. As discussed previously, these CCEMG equations also included cross-sectional averaged variables for economic growth, consumer prices, energy fuel prices, trade openness, government expenditures, and investment share.[7]

First, based upon the findings from Kremer et al. (2013), the CPI changes were separated into two individual components by differentiating CPI increases exceeding 2% per year from all other CPI

[7] Applying additional lagged values for the cross-sectional average variables severely restricted the degrees of freedom in each panel estimate, given the number of included variables.

changes. The coefficient for the former was -.134 and significant at the 1% level (z= -2.34), while the coefficient for the latter was -.032 and insignificant (z= -0.32). Accordingly, all further estimates discussed below include the former term but drop the latter term.

And second, energy fuel price changes after the Great Moderation were separated from all other energy fuel prices during the previous period. Based upon findings in McConnell and Quiros (2002), this moderation period covers the 1983-2016 period. The coefficient for energy fuel prices over the full sample was consistently significant and negative, but its effect was significantly lower after the Great Moderation, as discussed below. Although statistically insignificant, a dummy variable was also entered to account for any shift in the constant term during the moderation period, thereby allowing a more refined estimate of the response to later energy fuel price increases.

Full results for this revised equation are shown in the first column of Table 4 (labeled as Inst). Except for the post-1982 dummy variable (mod), all coefficients are significant with the correct sign at least at the 5% level and many like those for the energy fuel prices are significant at the 1% level. Economic growth responds positively to greater trade openness (D.OpenTrade) and investment's rising share in the economy (D.Investment) and negatively to higher past inflation (L.D.CPI>2%), more government expenditures relative to GDP (D.GovExp), and higher energy fuel prices (D.Energy). Other than energy fuel prices, the series are entered into the equation as control variables and are not the focus of the current analysis.

Table 4

The analysis emphasizes the importance of underlying baseline conditions in shaping the economy's response to energy price changes. If one views that the response to energy fuel prices after 1982 is more likely, these estimates show that a 10% energy price increase dampens economic growth by -0. 15%.[8] The table reports this result as -0.015 in the row labeled price effect immediately below the full set of coefficients. It is derived as the simple difference between the coefficients for the full energy price series (D.Energy) and for the post-1982 energy price series (D.Energy*mod). Although many different sectors use energy while oil is consumed primarily for transportation, it is interesting to observe that this response is similar to recent estimates of the USA economy's short-run adjustment to supply-side oil price shocks.[9] If one is concerned that the pre-1983 conditions may return through a higher baseline inflation rate or some other factor, it is possible that the response could be substantially higher, but one cannot draw this conclusion without further research.

The significant CIPS statistic in the table indicates stationarity in the equation's residual term when the Pesaran (2007) test for heterogenous panels with cross-section dependence is applied. In addition, the insignificant CD statistic indicates that the specification has adjusted appropriately for cross-sectional dependence in panel errors. Applying the Pesaran (2015) cross dependence (CD) test does not reject weak cross-sectional dependence, which occurs when the correlation between units in the same period converges to zero as the number of panels and time periods goes to infinity.

The table reports the coefficient for the error-correction term for each specification in the last row (labeled as the EC term) when the equation is estimated explicitly as an error-correction model. As opposed to estimating the equation in an unrestricted form, an error-correction term is recovered by taking the lag of the residuals of an equation containing the long-run relationship between the level variables. This lagged error-correction term is entered directly into the short-run relationship between the difference variables. These equations also use the cross-sectional average terms that adjust for cross

[8] As a reference, energy fuel prices are a real price index averaging 86.85 with a within-country standard deviation of 13.99 for the post-1982 period. Therefore, a one standard deviation change in this variable corresponds with a 16.1% price change relative to the mean value and an adjustment of 0.24% in real GDP growth. The GDP adjustment will be larger, of course, for energy price changes that depart substantially from this historical experience.

[9] Brown (2018) reviews more recent estimates of the macroeconomic impacts of oil supply shocks. He suggests a short-run elasticity of -0.018 in his updated assessment of the benefits from oil security policies.

dependence between countries. The error-correction coefficient indicates the speed of adjustment as the process converges from the short run to the long run. All values are negative but greater than -1 and therefore are consistent with convergence.

Section 3.1 discussed the specification issues and explained the instrumental variables for energy fuel prices in this equation. These variables have considerable power as the F-statistic for excluding them on the first round is 28.98 and lies substantially above the commonly used benchmark value of 10.

The second column (labeled as exog) provides another estimate of the same equation but with energy fuel prices entered as an exogenous series without any instrumental variables. The coefficients and their significance do not depart much from column (1) with the noticeable exception of the energy fuel price effect in the post-moderation era. It declines from -0.015 to -0.005 when energy fuel prices are not instrumented. These results confirm the previous analysis focused on the business cycles effect of crude oil prices that controlling for the endogeneity of energy prices is important.

The third column (labeled as w/o_mod) estimates the identical equation as in column (1) by assuming the same response to energy fuel prices before and after the Great Moderation. Although there are some differences between columns (1) and (3) in the coefficients in the lagged level variables, the most pronounced finding is that this equation results in a substantially higher energy price effect of -0.058.

The remaining three columns demonstrate that the results shown in the first column are robust to other modifications applied to these estimates. These adjustments do not change the significance of any variable and the coefficients for most variables do not depart much from the instrumental estimates in column (1). Most importantly, the table shows that the energy fuel price effect for the post-1982 period is remarkably similar regardless of the specification. It ranges between -0.012 and -0.015 and differs little from column (1).

Column (4) controls for the Great Recession through a dummy variable for 2009 in all panels. The dummy variable for this year is significant but the coefficients for the other variables are similar to those in column (1). For the estimates shown in column (5), several major events are removed because they may be important outliers. German output plunged in 1990 during the reunification of its east and west. In addition, recorded GDP in Ireland appeared to be extremely high in 2015, growing by more than 20% in the macroeconomic history database. It has been noted that the Irish GDP may be capturing the recent relocation of multinational corporations rather than simply economic activity. (See https://www.oecd.org/sdd/na/Irish-GDP-up-in-2015-OECD.pdf (accessed 2/7/2022)). Although both the German and Irish events can be very important for an evaluation focused exclusively on individual countries, our focus lies with understanding representative results from all countries in the panel. Excluding the German reunification in 1990 and the Irish boom in 2015 from the sample did not materially affect the relationships from column (1). Finally, the analysis expands the data set to include the experiences of the decade of the 1960s with results reported in column (6). Inflation was low and energy prices were remarkably stable during this earlier period. As a result, the CPI effect is lower in absolute terms than in the first column at -0.050 rather than -0.095 and is significant at only the 10% level. The energy price effect for the period prior to the Great Moderation (D.Energy) also appears less than in column (1). Unlike the balanced estimates in the other columns, this expanded data set covered in the last estimate is unbalanced because the German panel began in 1962 and the Australian panel began in 1972.

It is worth noting that the CIPS statistic continues to support the stationarity of the residual term in these other equations summarized in this table. Although the cross-sectional average terms have removed much of the cross-sectional dependence between panels, the CD statistic in all but the last alternative specification rejects weak cross-sectional dependence at the 5% level. This finding suggests that the parameter estimates in the alternative specifications may be inconsistent and statistical inferences may be incorrect, because the CD test rejected weak cross-section dependence (Kapetanios et al. 2011). Only making adjustments to the standard errors (e.g., via Driscoll and Kraay 1998) may not be sufficient, because cross-sectional dependence can cause bias problems as well as inefficiency.

5. Panel-Specific Responses

The primary objective has been to develop a representative set of coefficients for all countries as a group rather than individual estimates for each country in the sample. Although allowing countries to have heterogeneous coefficients provides more consistent estimates of the average effect for all countries relative to pooled estimates, individual responses can be unreliable and often vary substantially from each other. Nevertheless, comparing individual responses with each other reveals some relevant information about the role played by energy intensity relative to GDP.

Table 5 combines individual country results that are important for this investigation. The first column reports the average energy intensity (energy consumption per GDP measured in 1000 Btu/2015$ GDP PPP) over all years (1983-2016), except for Germany (1991-2016). This average energy intensity variable will serve as a useful benchmark for discussing the country responses. Supplementing the aggregate energy intensity are average total energy exports and imports (both in quadrillion British thermal units) shown in columns (2) and (3), calculated over the same periods. The source of these data is the US Energy Information Administration, https://www.eia.gov/international/data/world (accessed 2/7/2022). Column 4 reports the individual country responses of real GDP to real energy fuel prices from the pre-1983 CCEMG results considered in Table 4, column 1, labeled as Inst. It is the panel-specific coefficient for D.Energy in that specification. Column 5 reports the individual country responses of real GDP to real energy fuel prices for the post-1982 period from the same specification. It is the sum of the panel-specific coefficients for D.Energy and D.Energy*mod in that specification. The bottom row of each column reports the average response across all countries that are the same values reported in Table 4.

Table 5

Energy prices should have a larger role in shaping economic performance in countries where the aggregate energy intensity (relative to GDP) is greater, *ceteris paribus*. Unfortunately, extracting such a relationship from the individual panel results may be very challenging because the mix of underlying conditions, wage and price institutions, and government policies may be very different across countries. The top portion of Table 6 reports simple bivariate regression analyses that explain a country's response both before and after 1982 as a function of its average energy intensity over this period.[10] With a negative and significant coefficient at the 1% level (column 1), aggregate energy intensity in a country appears to play a role in explaining its GDP response to the energy price in the pre-1983 period. The inverse relationship between energy prices and real GDP appears to be larger when that country's economy is more energy intensive. A similar specification focused upon the post-1982 period produces more ambiguous results and underscores the importance of other factors (like policies, energy exporter or importer, and price and wage stickiness) besides aggregate energy intensity that influence how economic output responds to energy price changes. When the sample includes all 18 countries, the coefficient for energy intensity (column 2) is again negative but reaches significance at only the 20% level, well below the customary 5% level for a significant result. When two obvious outliers[11] are dropped from the sample, the coefficient shown in column (4) becomes significant at the 1% level. However, there is no logical economic argument for excluding them because there are too few observations in these cross-country estimates. For completeness, this same specification that excludes these two observations continues to find a significant response for the earlier pre-1983 period, as shown in column (3).

Table 6

[10] An insignificant constant term has been removed in all equations discussed in this paragraph.
[11] The outliers include Canada with a very high aggregate energy intensity and Portugal with a relatively low energy intensity.

The middle portion of this table shows a similar set of regressions where total energy exports divided by total energy imports (both expressed in quadrillion British thermal units) replaces aggregate energy intensity as the independent variable. There exists a strong positive correlation between these two independent variables because economies based upon large domestic energy resource endowments often attract energy-intensive industries like refining, chemicals, and metals production. In all cases, a significant inverse relationship between energy prices and real GDP appears to be larger when that country's economy exports more total energy than it imports. However, when both variables are included in the regression (shown in the bottom portion of the table), collinearity between the two variables makes it difficult to identify a significant effect for the export indicator. Meanwhile, aggregate energy intensity appears significant in three of the four sets of results. Given the limited degrees of freedom, the results from these individual panel estimates should be viewed as suggestive rather than robust.

6. Conclusions

In this analysis instrumental variables were used to differentiate supply-oriented energy price changes from other energy price changes. It provides estimates that higher energy prices induced by energy-supply shifts within major OECD countries have retarded economic growth modestly. When averaged across each of these economies, a ten percent increase causes annual economic growth to decline by 0.15% based upon the post-1982 period. Although advanced economies use oil quite differently from other major fuels, it is interesting that this effect is comparable to previous estimates on the short-run impacts of crude oil prices over similar time periods. These estimates capture one dimension of the effects induced by environmental taxes that raise fuel prices. However, as discussed briefly in section 2 above, environmental taxes may also influence aggregate spending depending upon how the tax revenues are redistributed back into the economy and if they are combined with tax reforms that reduce other distortionary taxes on labor and capital. Moreover, environmental taxes may ultimately improve the quality of the environment and therefore shift spending away from expenses like healthcare services towards more productive uses like education.

These results also confirm previous findings that the response to energy prices caused by energy-supply shifts is less under current conditions than during the 1970s. As suggested by others, an important factor may be that monetary and fiscal policies were more restrictive and less accommodating in the earlier period, when inflationary pressures coexisted with stagnating economic conditions. When inflation rates initially are relatively high, governments may be more reluctant to adopt monetary and fiscal policies because they fear that these actions could substantially worsen the next round of inflation rates and eventually economic growth rates. An important caveat is that the response to supply-side energy price changes is very much contingent on the underlying economic conditions prevailing at the time of the energy-supply shift. This reminder should be a cautionary tale about extending recent GDP responses to energy price changes for the current energy market disruptions caused by the Russian invasion of Ukraine.

Although environmental taxes often impose lower costs than other policy options, governments often resort to mandates restricting the use of certain fuels and other non-economic strategies for political and societal reasons. When these mandates and other actions accelerate the transition towards newer sources that may entail higher initial costs, policy analysis will need to incorporate an estimate of how higher energy costs shape economic growth. The current analysis provides a long-term perspective on this important topic that will improve model-based and other policy analysis of a range of different options.

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Table 1. Data Summary

Variable	Mean	Standard Deviation	Coeff. of Variation	Minimum	Maximum
GDP	9.637	0.381	0.040	8.358	10.635
CPI	4.189	0.893	0.213	1.531	5.948
ENERGY	4.335	0.233	0.054	3.699	4.947
OpenTrade	0.518	0.160	0.309	-0.013	1.839
GovExp	0.249	0.046	0.186	-0.093	0.392
Invest	0.233	0.031	0.132	0.121	0.376
D. GDP	0.024	0.025	.	-0.090	0.204
D.CPI	0.045	0.040	.	-0.055	0.287
D.ENERGY	0.006	0.071	.	-0.243	0.425
D.OpenTrade	0.005	0.082	.	-1.066	1.007
D.GovExp	0.001	0.019	.	-0.329	0.119
D.Invest	0.000	0.014	.	-0.082	0.113

Notes: Real GDP (GDP), CPI and Energy Prices (ENERGY) are in logarithms.
Open Trade (OpenTrade), Gov Expenditures (GovExp) and Investment (Invest) are % of GDP.
Within-country standard deviations, minimums and maximums are reported.
D. denotes change.

Table 2. Pesaran (2007) Panel Unit Root Tests, All Years

	Lags			
	0	1	2	3
No Trend				
GDP	1.46	0.61	1.2	0.66
CPI	-0.34	-3.40**	-1.21	-0.47
ENERGY	-1.26	0.49	0.9	1.8
OpenTrade	-1.82**	-3.05**	-3.06**	-3.22**
GovExp	-0.37	0.21	0.37	0.48
Invest	-0.99	-2.78**	-2.24**	-0.88
D.GDP	-16.59**	-11.7**	-9.00**	-7.05**
D.CPI	-10.38**	.	-9.19**	-7.21**
D.ENERGY	-19.8**	-15.85**	-11.27**	-7.90**
D.OpenTrade	.	.	.	.
D.GovExp	-18.45**	-13.25**	-9.02**	-6.95**
D.Invest	-17.48**	.	.	-8.53**
Trend				
GDP	2.34	0.81	1.12	1.2
CPI	-1.63	-6.86**	-2.74**	-2.58**
ENERGY	-1.59	0.21	1.27	2.44
OpenTrade	0.11	-0.96	-0.81	-0.91
GovExp	-0.39	0.30	0.31	0.43
Invest	0.96	-1.12	-0.54	0.44

Notes:
*** p<0.05, ** p<0.01. D.=first difference operator.**
Null hypothesis is the series is I(1). Real GDP, CPI and Energy Price variables are in natural logs; others are percent of GDP.

Table 3. Coefficients in Unweighted and Outlier-Robust Means Methods

Variable	cce	ccerobust
D.CPI	-0.131*	-0.161*
D.ENERGY	-0.022	-0.023
D.OpenTrade	0.219**	0.209**
D.GovExp	-0.296**	-0.149**
D.Invest	0.653**	0.652**
L.GDP	-0.353**	-0.348**
L.CPI	-0.049	-0.049
L.OpenTrade	0.088**	0.044**
L.Invest	0.273**	0.265**
_cons	0.228	0.181

Notes: * p<0.05; ** p<0.01
D. denotes change; L. denotes lag

Table 4. CCE-Mean-Group Estimates for Real GDP Growth

	inst	exog	w/o_mod	recession	ger_ire	sixties
	b/se	b/se	b/se	b/se	b/se	b/se
L.D.CPI>2%	-0.135*	-0.131*	-0.152**	-0.132*	-0.122*	-0.095**
	(0.057)	(0.056)	(0.057)	(0.057)	(0.059)	(0.035)
D.OpenTrade	0.169**	0.165**	0.165**	0.164**	0.173**	0.197**
	(0.047)	(0.047)	(0.050)	(0.041)	(0.046)	(0.043)
D.GovExp	-0.245**	-0.267**	-0.255**	-0.253**	-0.258**	-0.267**
	(0.069)	(0.071)	(0.074)	(0.068)	(0.068)	(0.083)
D.Invest	0.671**	0.684**	0.701**	0.646**	0.691**	0.629**
	(0.091)	(0.095)	(0.087)	(0.095)	(0.095)	(0.080)
L.GDP	-0.434**	-0.431**	-0.456**	-0.419**	-0.415**	-0.364**
	(0.053)	(0.052)	(0.053)	(0.054)	(0.054)	(0.047)
L.CPI	-0.095**	-0.065	-0.056	-0.076*	-0.115**	-0.050
	(0.037)	(0.037)	(0.036)	(0.037)	(0.034)	(0.031)
L.OpenTrade	0.080*	0.095**	0.059	0.089**	0.079**	0.096**
	(0.032)	(0.034)	(0.040)	(0.030)	(0.030)	(0.030)
L.Invest	0.435**	0.440**	0.489**	0.441**	0.409**	0.250**
	(0.098)	(0.097)	(0.104)	(0.102)	(0.104)	(0.077)
mod	0.003	0.004		0.002	0.003	0.004
	(0.006)	(0.007)		(0.006)	(0.006)	(0.006)
D.Energy*mod	0.071**	0.039		0.056**	0.071**	0.046*
	(0.017)	(0.021)		(0.017)	(0.019)	(0.019)
D.Energy	-0.086**	-0.044**	-0.058**	-0.070**	-0.088**	-0.058*
	(0.023)	(0.016)	(0.018)	(0.019)	(0.022)	(0.026)
recess				-0.009		
				(0.005)		
_cons	0.028	0.200	0.294	-0.107	0.082	0.075
	(0.595)	(0.609)	(0.567)	(0.549)	(0.451)	(0.269)
Price effect	-0.015	-0.005	-0.058	-0.014	-0.017	-0.012
Observations	808	808	808	808	806	976
RMSE	0.009	0.012	0.010	0.009	0.008	0.011
CIPS	-15.37**	-17.84**	-16.10**	-17.79**	-18.30**	-20.25**
CD	1.61	2.04*	2.71**	2.49*	2.09*	1.61
EC term[#]	-.537**	-.435**	-.506**	-.524**	-.403**	-.423**

* p<0.05, ** p<0.01

Estimated explicitly from an error-correction model.

Table 5. Individual Country Intensity and Responses

Country	Intensity	Exports	Imports	Post_1982	Pre-1983
Australia	6.62	9.46	4.66	-0.041	0.045
Belgium	6.23	0.49	2.48	-0.063	-0.063
Canada	10.86	16.61	12.38	0.042	-0.024
Switzerland	3.07	0.60	1.23	0.021	-0.085
Germany	4.22	5.53	14.30	-0.142	-0.314
Denmark	3.61	0.74	0.82	0.012	-0.092
Spain	4.00	1.49	5.08	0.032	0.017
Finland	6.44	0.42	1.18	-0.097	-0.221
France	4.70	4.76	10.23	-0.003	-0.090
United Kingdom	4.62	8.88	9.30	0.038	0.040
Ireland	3.27	0.07	0.51	0.067	0.012
Italy	3.39	1.31	7.12	0.006	-0.092
Japan	4.54	3.62	20.42	-0.091	-0.221
Netherlands	5.77	2.73	3.77	-0.009	-0.069
Norway	7.84	8.17	1.79	-0.095	-0.123
Portugal	3.37	0.15	0.90	0.248	0.017
Sweden	6.61	1.39	2.23	-0.124	-0.148
United States	7.22	72.61	91.55	-0.073	-0.140
Average				-0.015	-0.086

Notes: Intensity is the average energy intensity (energy consumption per GDP measured in 1000 Btu/2015$ GDP PPP) over 1983-2016, except for Germany (1991-2016). Exports (imports) are total energy quadrillion BTUs for the same period. Post_1982 and Pre_1983 are the energy price coefficient in the economic growth equation for years after 1982 and prior to 1983, respectively. Average (the last row) is the simple unweighted mean of the country effects.

Table 6. Regressions of Country-Specific Responses

	(1) pre-1983	(2) post_1982	(3) pre-1983	(4) post_1982
intensity	-0.0144**	-0.00429	-0.0180**	-0.00833**
	(-3.36)	(-1.35)	(-4.10)	(-3.60)
N	18	18	16	16
F	11.27	1.818	16.82	12.96
rmse	0.102	0.0886	0.0999	0.0573
export/import	-0.0369*	-0.0195**	-0.0382*	-0.0240**
	(-2.88)	(-3.63)	(-2.68)	(-4.79)
N	18	18	16	16
F	8.285	13.19	7.174	22.98
rmse	0.123	0.0883	0.130	0.0653
export/import	0.0182	-0.0125	0.0267	-0.000794
	(0.82)	(-1.01)	(1.22)	(-0.08)
intensity	-0.0174*	-0.00220	-0.0228**	-0.00818*
	(-2.80)	(-0.44)	(-3.87)	(-2.30)
N	18	18	16	16
F	5.248	6.553	9.155	7.796
rmse	0.104	0.0905	0.0999	0.0593

Notes: t statistics in parentheses
Robust standard errors
* p<.05, ** p<.01

Appendix

Country Variable Charts

The study uses an almost balanced data set for the major wealthy countries with a long history of published collected statistics. Figures A.1-A.6 visually display the level for each variable by country. With perhaps the exception of open trade after 2012 and government expenditures after 2014 in Ireland, no obvious outliers are apparent. Excluding the post-2012 Irish experience from the post-1982 sample does not appreciably alter the magnitudes or significance of the coefficients.

Country-Specific Residuals

Figure A-7 displays the actual change in real GDP by country and their residuals from the main CCEMG estimates (Table 4, column 1). The residuals appear well behaved and do not depart substantially from zero relative to the actual economic growth rates. There are no obvious clear outliers for the most part, except for Ireland in 2015, when actual growth in the history database exceeded 20% and its residual in the equation reached about 9% (not shown in the graph). As discussed in the main text, the Irish GDP may be capturing the recent relocation of multinational corporations rather than simply economic activity.

Figures A-1 through A-7

Estimation Routines

We used the STATA xtdcce2 program developed by Ditzen (2016). The CD statistic used by xtdcce2 tests for weak cross dependence (rather than independence) between the panel errors. The alternative hypothesis is strong cross dependence. We used the STATA pescadf program developed by Piotr Lewandowski to estimate the CIPS statistic and the xthst program developed by Bersvendsen and Ditzen (2021) for testing whether country-specific slope coefficients were homogeneous.

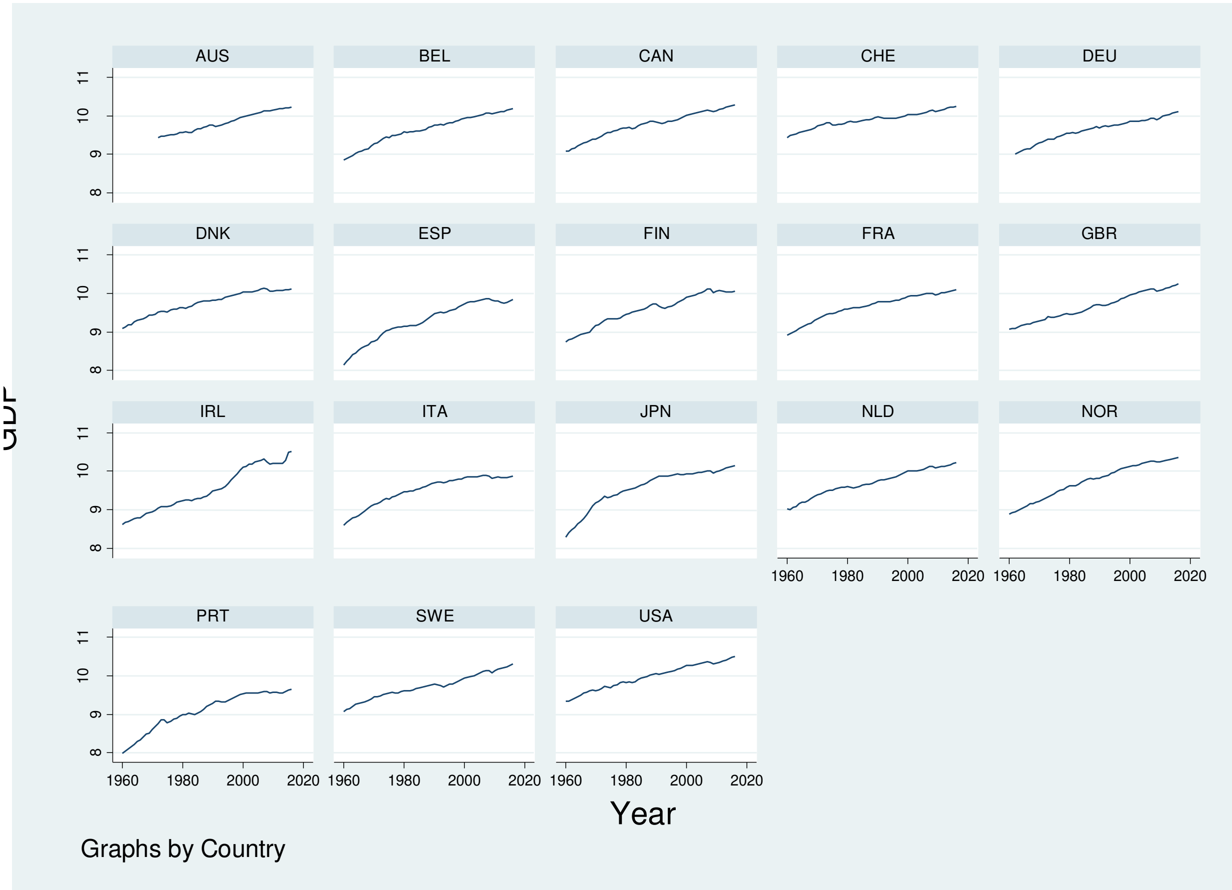

Figure A- 1: Country Real GDP Levels (log) by Year

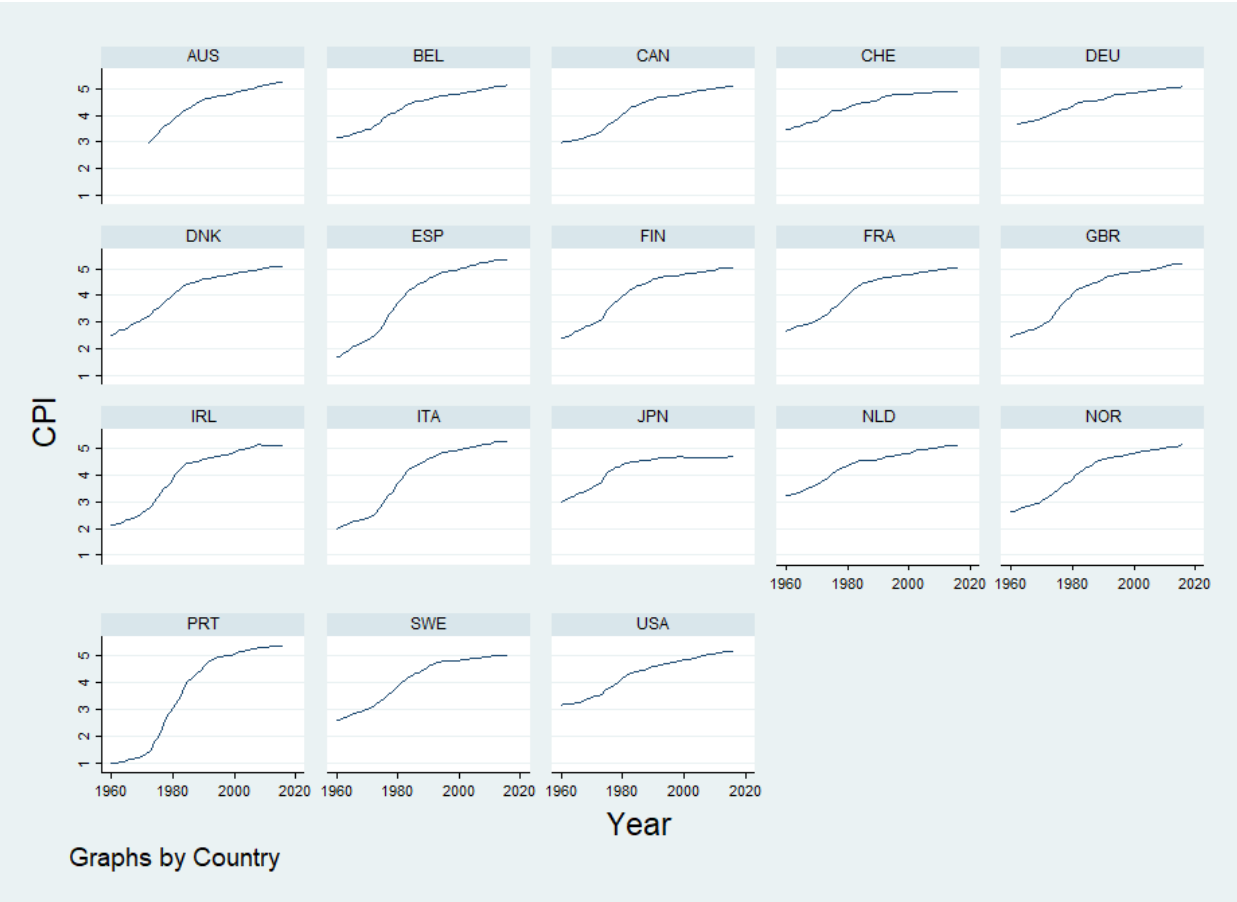

Figure A- 2. Country CPI Levels (log) by Year

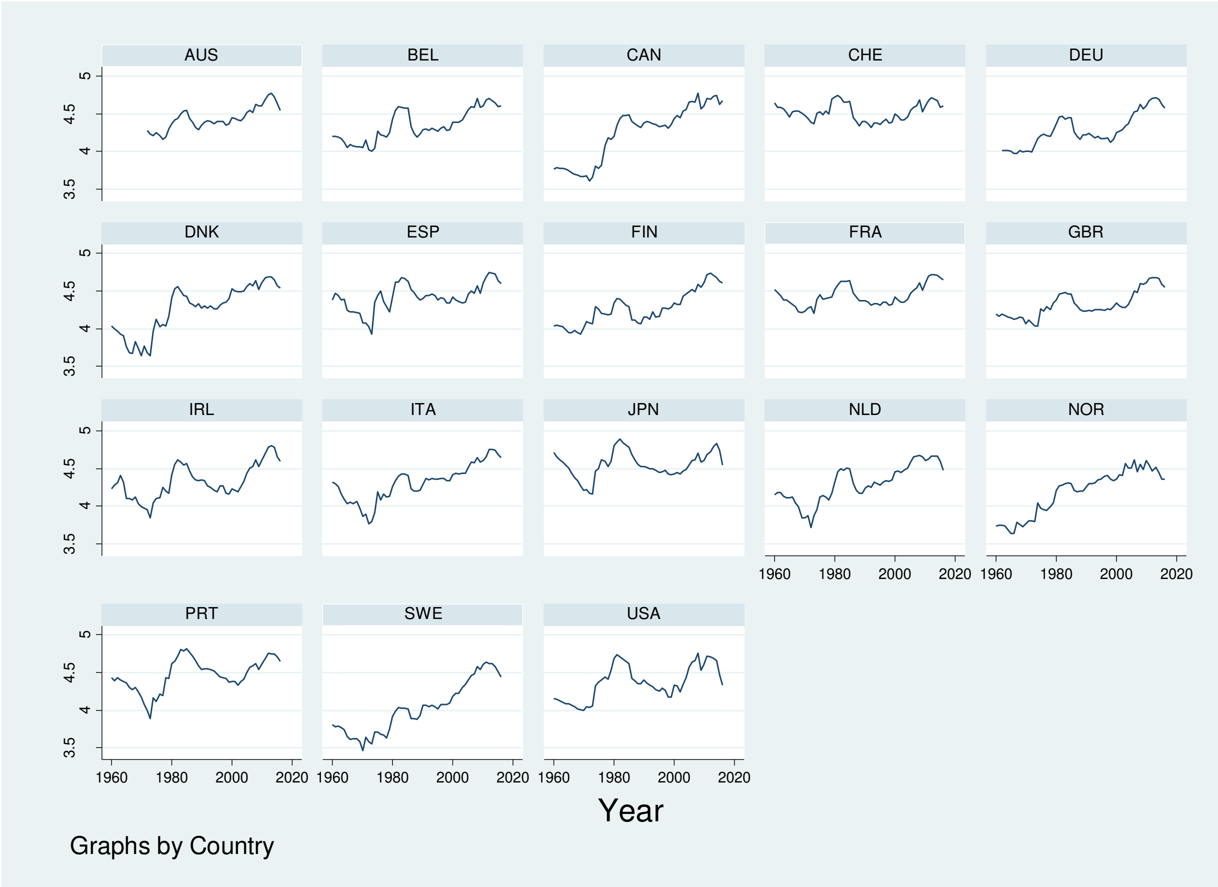

Figure A- 3. Country Energy Price Levels (log) by Year

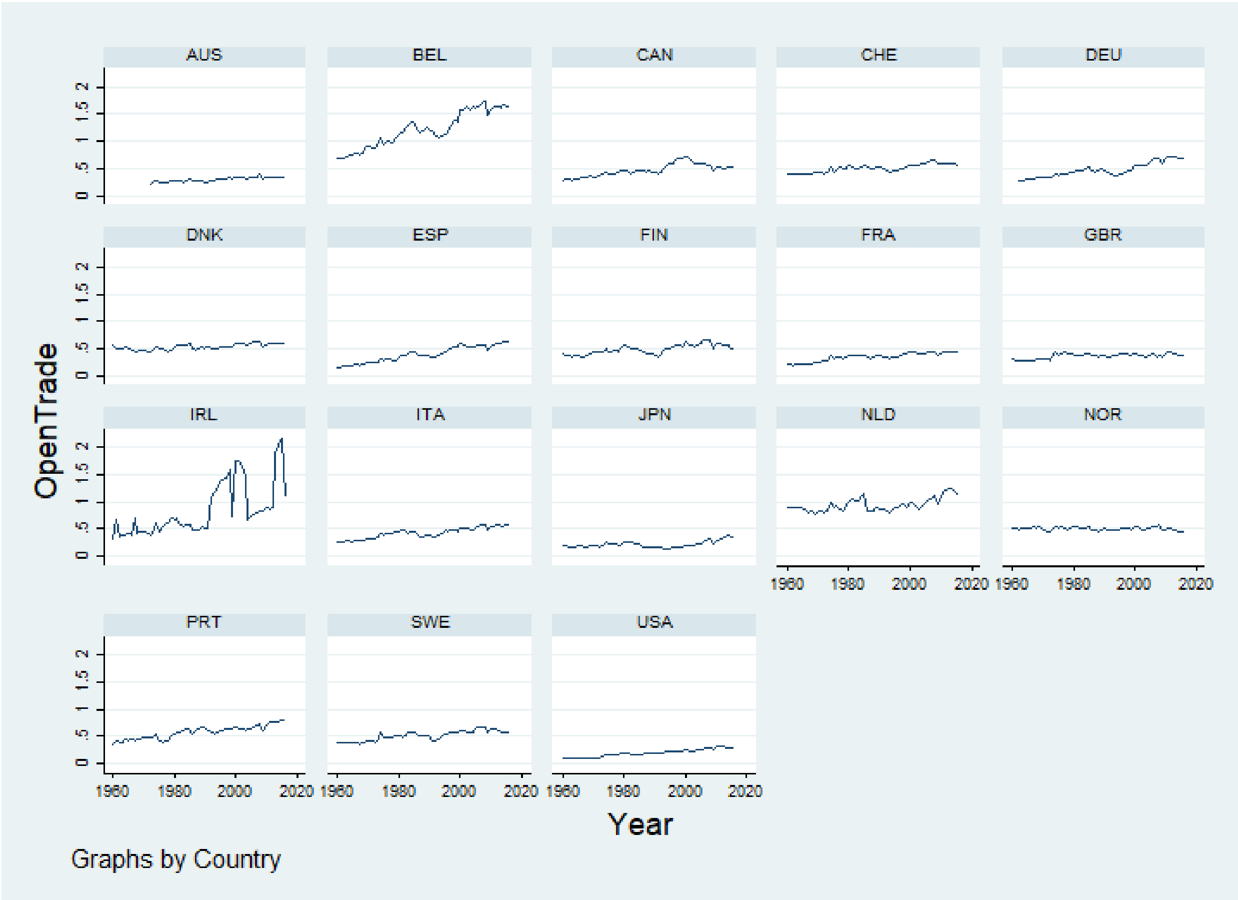

Figure A- 4. Country Open Trade (as % of GDP) by Year

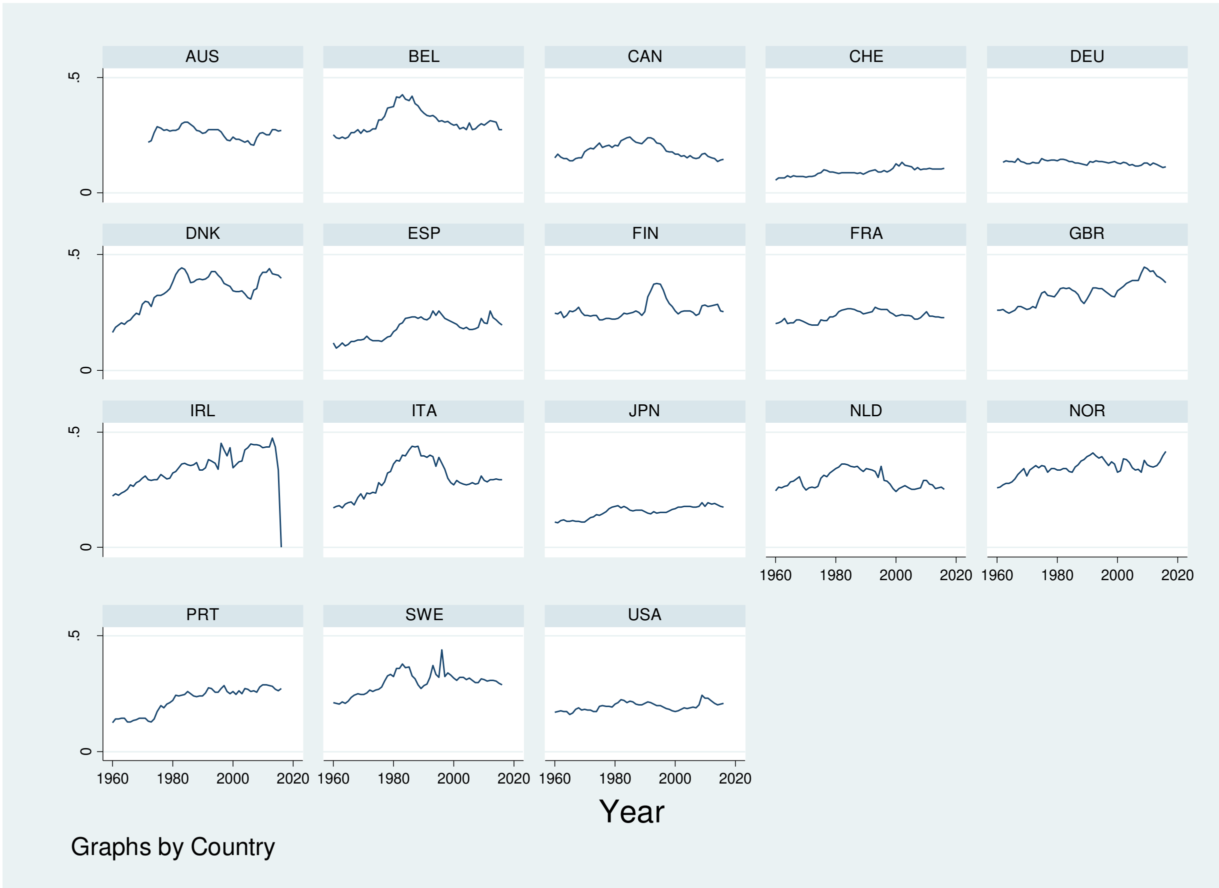

Figure A- 5. Country Government Expenditures (as % of GDP) by Year

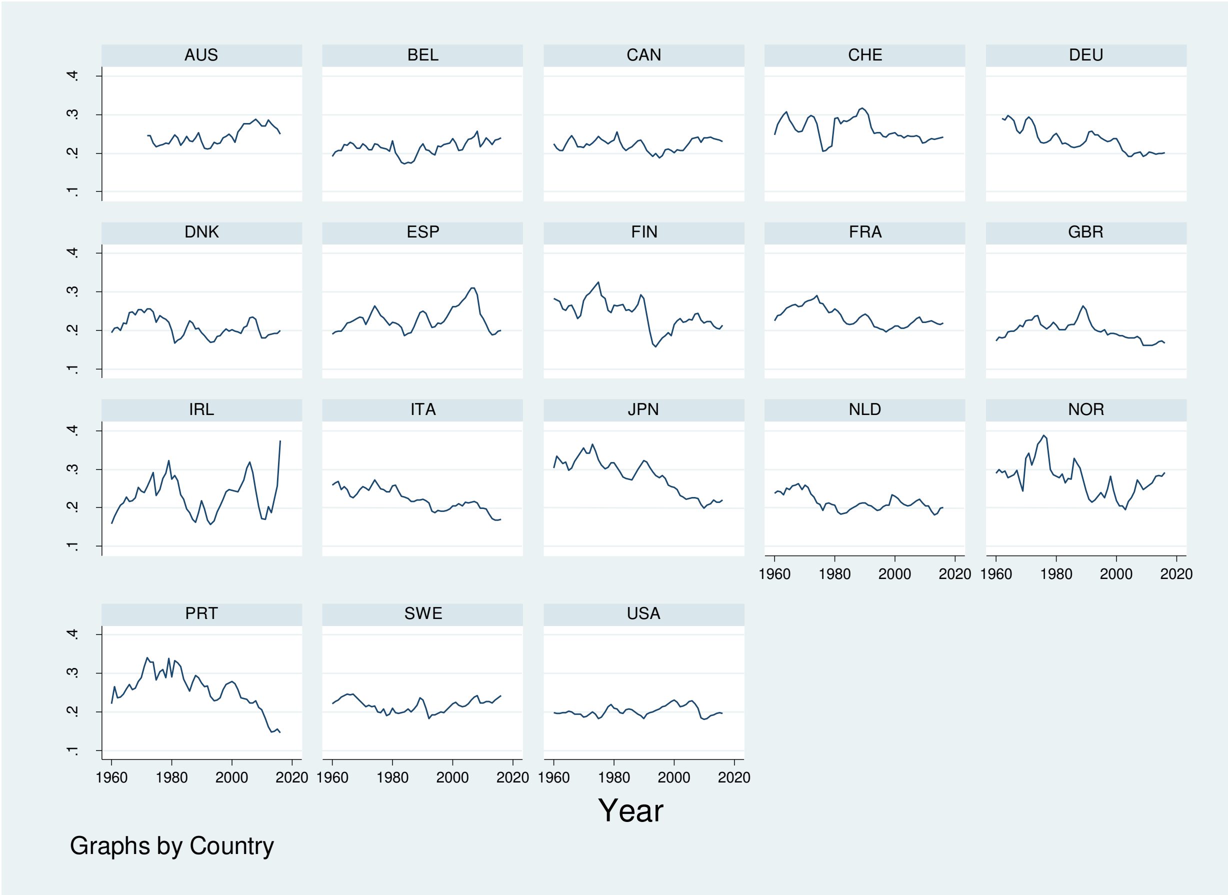

Figure A- 6. Country Investment (as % of GDP) by Year

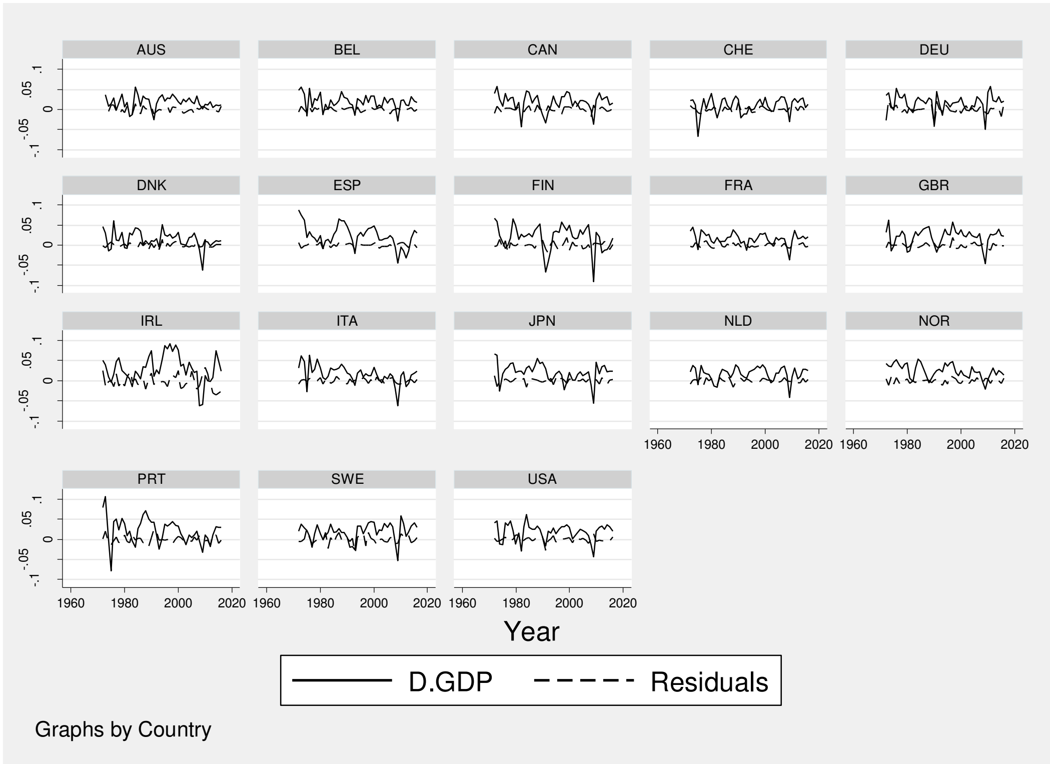

Figure A- 7. Actual Change in Real GDP and Residuals by Country