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Climate change and economic growth: Evidence for European countries

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Abstract

Climate change is very likely to affect economies and the welfare of people around the world. In order to design appropriate policy responses, the economic effects of climate change should be known. One strand in the literature empirically estimates the growth effects of climatic variations. However, those studies often neglect economic variables that have proven to be robust in explaining economic growth. Further, often they fail to check for the robustness of their results. In this study we apply panel estimation techniques to analyze the relation between climate change and economic growth for 24 European economies for the period from 2002 to 2019 based on different specifications. We do not find a statistically significant robust relationship between the temperature change and economic growth just as for precipitation that does not exert a significant effect on growth. As regards the institutional and macroeconomic control variables the rule of law, the fiscal variable and the output gap are statistically significant.

Keywords: Climate change, economic growth, policy implications, robustness
JEL: O47, Q54

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1 Introduction

Modern research to detect the forces of economic growth using econometric methods has started in the 1950's with a seminal paper written by Solow (1957) who implicitly builds on Tinbergen (1942) who was the first to integrate a time index in the aggregate production function. Solow's great merit was to show how a measure of the technical progress can be estimated from real world data accounting for that part of GDP growth that is not explained by increases in capital and labor input.

In the following decades numerous empirical studies have been undertaken aiming to enhance our understanding of the process of economic growth. But, researchers often limit their analyses to only a small number of explanatory variables so that the question arises how valid their results are. As regards that problem Leamer (1985) states that "We must insist that all empirical studies offer convincing evidence of inferential sturdiness. We need to be shown that minor changes in the list of variables do not alter fundamentally the conclusions, nor does a slight reweighting of observations, nor correction for dependence among observations, etcetera, etcetera." (Leamer, 1985, p. 308). Therefore, Levine and Renelt (1992) performed an extreme-bounds analysis, based on Leamer (1983), where they investigate which variables always exert a statistically significant effect in explaining economic growth, independent of which other variables are included in the regression.[1] They find that only few variables are robust as defined by them, such as the investment share, trade and the initial level of GDP. Sala-i-Martin (1997) argues that the extreme-bounds analysis is too restrictive since it allows only a zero-one labeling, i.e. a variable is either robust or it is not. Rather, he suggests to call a variable robust if 95% of the density of an estimated coefficient lie to the right or to the left of zero. Proceeding like that he finds additional variables to be robust such as political variables. Bruns and Ioannidis (2020) analyze whether the forces of economic growth change over time or remain the same independent of which time period is considered. They find that inferences on growth determinants are not stable across time periods. Nevertheless, variables such as the investment share and trade are statistically significant in the more recent growth period from 1960 until 2010.

Besides economic and political variables, the natural environment and the climate on

[1]For details as to that analysis, see Levine and Renelt (1992, p. 944).

earth can affect the development of economies, too. The global climate, for its part, is very likely affected by the accumulation of greenhouse gases (GHGs) in the atmosphere, like carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). An increase of GHGs in the atmosphere raises radiative forcing leading to higher temperatures on earth with the relation described by an approximately linear relationship. But, the radiative forcing of carbon dioxide, for example, is given by the natural logarithm of that GHG relative to the pre-industrial level and all other GHGs can be converted into CO_2 equivalents, see Greiner and Semmler (2008, p. 61), and for more details the natural science literature cited there.[2] This implies that the temperature does not rise linearly with a rising GHG concentration as erroneously stated by SRU (2019, p. 36). However, even if there is very strong evidence that the accumulation of GHGs raises the average surface temperature on the earth (see e.g. Arias et al., 2021), it must be stated that the climate system is an extremely complex system such that there is strong uncertainty as regards its sensitivity with respect to higher GHGs (cf. Meinshausen et al., 2009, Meinshausen et al., 2011, section 4.1.3, Sherwood et al., 2020). A simple example is provided by Greiner and Semmler (2005) who have shown that feedback mechanisms affecting the Albedo of the earth can lead to multiple equilibria in a standard growth model, where a zero-dimensional climate module had been integrated. This means that the average surface temperature does not converge to its new relatively low equilibrium value, but to the high equilibrium value, once a certain temperature threshold is passed.

Further, models of the Coupled Model Intercomparison Project Phase 5 (CMIP5), resorted to by the Intergovernmental Panel on Climate Change (IPCC) for its 5th assessment report published in 2013/2014, do not perform well in some respect. For instance, Lewis and Curry (2018) show that the equilibrium climate sensitivity and the transient climate response of the majority of CMIP5 models do not match the observed warming during the historical period. A similar result is obtained by McKitrick and Christy (2018) who compare the model projections of CMIP5 models with the actual temperature of the troposphere in the tropics. They find that most of the models show a significant and large warm bias in that layer.[3] That problem still holds for most of the CMIP6

[2]Etminan et al. (2016) show that for very high values of GHGs, the relation changes. But, the basic form remains the same, i.e. for CO_2 it is given by the ln and for N_2O and CH_4 by the square root.

[3]Frank (2019) detects that CMIP5 models produce a systematic calibration error in simulated tropo-

models. Thus, Voosen (2022) points to a U.N. report stating that many climate models predict temperature increases that are not compatible with actual temperature changes. Hence, the outcome of studies that forecast dramatic effects and that are based on some of the next-generation climate models that predict a fast temperature increase should be considered with care. Therefore, one should think about moving away from a "model democracy" and to a "model meritocracy" when projections with respect to temperature changes are made.

Another contribution is presented by Scafetta (2023) who considers 38 models from CMIP6 and groups them in 3 subgroups, a subgroup predicting a low equilibrium climate sensitivity (ECS), a subgroup with a medium ECS and one consisting of models predicting a high ECS. He finds that only the models of the low subgroup are compatible with the surface-based temperature change between 1980-1991 and 2011-2021, while none of the models is compatible with the satellite-based UAH-MSU-lt temperature record. A similar result was obtained by McKitrick and Christy (2020) who detected that the bias in CMIP6 models does not only occur for the troposphere in the tropics, as it was the case for CMIP5 models, but that it is now observable globally as well and not only in the tropics. Vrac et al. (2023) analyze whether CMIP6 models are able to simulate changes in the temperature-precipitation correlations caused by climate change. They find that those models cannot replicate the correlations over the historical period 1980-2019, but are biased. They conclude that the models should not only be improved as regards their ability to predict univariate climate variables, such as temperature and cloud parametrization for example, but they should be improved with respect to multivariate biases, too.

Lewis (2023) examined the influential paper by Sherwood et al. (2020) that was often cited in the relevant chapter of the IPCC 6th assessment report. He found that the median of the ECS for a doubling of GHGs amounts to 2.16 °C, which is considerably lower than in Sherwood et al. (2020), with a smaller confidence interval, when the subjective Bayesian statistical method, with an investigator-selected prior distribution, is replaced by an objective Bayesian method with computed, mathematical priors. Vogel et al. (2022) refute an important line for a high climate sensitivity. They find that the feedback effect of a higher GHG concentration is much smaller than assumed in those climate models that

spheric thermal energy flux.

predict a strong temperature rise. This holds because real-world observations suggest that a weak trade cumulus feedback, i.e. cloud feedback, is more plausible than a strong one. In general, it must be stated that the feedback effects of clouds that strongly affect the temperatures are not yet understood and cause great uncertainty in climate models (see e.g. Mülmenstedt et al., 2021, Furtado et al., 2023, Hill et al., 2023). Model uncertainty also results from the unpredictability of volcano eruptions and from the complexity of processes linking the eruption to the climate response (cf. Chim et al, 2023, and Zanchettin, 2023). As regards the feedback effect of thawing permafrost soils Keuschnig et al. (2022) obtain a similar result because they find that changes in soil properties, plant cover and microbial communities will reduce methane emissions in former permafrost soils. Other authors point out that the effect of GHGs receives too high a weight in climate models, while natural factors receive too little attention, see e.g. Gervais (2016), Ollila (2017), Lightfoot and Mamer (2017), Connolly et al. (2023), Stefani (2021), Kim et al. (2022), Ollila and Timonen (2022), Omrani et al. (2022). Smirnov and Zhilyaev (2021) argue that climate models do not take into account the thermodynamics of the atmosphere and radiation field and ignore the Kirchhoff law (Kirchhoff, 1860), stating that radiators are absorbers at the same time. Consequently, the greenhouse effect of CO_2 is heavily overestimated in those models.

These studies demonstrate that there is great model uncertainty as regards the climate system of the earth and one should be careful when using the outcome of those models for policy recommendations. The uncertainty holds although those models are characterized by a high degree of sophistication and are very complex requiring a great amount of computing capacity.

Despite those high uncertainties with respect to the climate models, changes in the climatic conditions are likely to influence the economic system of societies. For example, more extreme weather events cause economic damages and require resources that cannot be used for consumption and/or for investment, although it must be noted that the empirical evidence for more extreme events is small, with the exception of heatwaves (see Ranasinghe et al., 2021, p. 1856, table 12.12, column 3, Alimonti and Mariani, 2023, Zhang et al., 2023, and similar Lomborg, 2020). In general, it can be expected that changes in the climate show effects on the growth rates of aggregate GDP. But, the uncertainty regarding the economics of the climate change may be still larger than for the climate models which is reflected by the wide range for the estimates of climate related damages. This holds for specific sectors in the economy (see e.g. Nocera et al., 2015, Neumann et al., 2020) and for the macroeconomy as well (cf. Keller and Nicholas, 2015, Nordhaus and Moffat, 2017, Botzen et al., 2019). For example, Nordhaus and Moffat (2017) estimate damages of global warming to amount to 2.04 ($\pm$ 2.21) percent of income when the average global surface temperature rises by 3 degree Celsius. Newell et al. (2021) state that there is large model uncertainty as regards the effect of global warming on the macroeconomy. They use cross validation to evaluate 800 model specifications where they use GDP growth and, alternatively, the level of GDP as the dependent variable that is explained by the temperature, by the change of temperature, by precipitation and by time fixed effects and by country-specific time trends. They find that growth models are associated with large uncertainties reflected by the fact that the 95% confidence interval for GDP impacts in 2100 ranges from GDP losses of 84% to gains of 359%. GDP level models, however, go along with less uncertainty and have a smaller 95% confidence interval between -8.5% and +1.8%, centered around losses between 1-3%. Two other examples analyzing the effect of climate change on economic growth are Burke et al. (2015) and Kotz et al. (2021) who perform panel studies where the growth rate represents the dependent variable that is regressed on climatic variables such as the temperature, precipitation, temperature variability and on changes of those variables.

Those studies, however, focus on only one potentially relevant bundle of physical factors while neglecting economic variables that have turned out to be important in explaining economic growth, thus, giving rise to the problem of omitted variables. From an econometric point of view this can lead to inconsistent estimations of the coefficients when the explanatory variables are correlated with the residuals. Even if that problem can be overcome technically in fixed effects panel regression models by introducing dummies, as noted and done in Kotz et al. (2021, p. 326), the problem of missing economic variables remains such that the estimated model may not be a good proxy for the true data generating process and may not yield the true effect of climate variables. Barker (2022) provides an example showing that the relation between economic growth and the temperature change, detected in a growth regression, does not turn out to be robust. He tests the outcome of the paper by Colacito et al. (2019) and shows that the removal of a small number of observations drastically changes the qualitative effect of climate change on economic growth. Thus, the removal of data before 1990 would have raised the estimate by almost three times implying that global warming would nearly eliminate economic growth in the USA. Further, allowing for non-linearities may change the outcome, too, and can lead to positive growth effects of higher temperatures, as shown in detail by Barker (2022). This demonstrates that estimation results may be sensitive with respect to the data and with respect to the estimation method. Hence, results should be checked with respect to their robustness. The latter is particularly important when the outcomes form the basis for economic policy decisions. Policies that rely on non-robust results may generate huge welfare losses.

Another aspect that should be pointed out is that policies aiming to reduce GHG emissions may influence economic variables, too. For example, Kapfhammer (2023) finds that carbon taxes in Scandinavian countries reduce emissions, but, go along with adverse effects on economic activity. Känzig (2023) comes to the conclusion that higher permit prices in the EU ETS gives rise to a persistent increase in consumer prices and to a temporary, but substantial decline in economic activity. However, it must be underlined that those outcomes are not robust. Thus, Bernard and Kichian (2021) do not find a significant impact of the carbon tax in British Columbia on GDP and Metcalf and Stock (2020) find no robust evidence that carbon taxes in European countries reduce employment or GDP growth. An important aspect when analyzing effects of fiscal variables is that the period budget constraint of the government should be taken into account. This holds because variations in one fiscal variable implies that another is affected, too. But, in order to avoid the problem of multi-collinearity one variable must be dropped and it should be that one where theory predicts that it does not affect the dependent variable, see Kneller et al. (1999, p. 174-175). In public finance terms this means that looking at the specific incidence of a tax does not yield a reliable picture of its growth effects. Rather, the analysis should focus on the budget incidence.

Our goal with this study is to empirically analyze whether there exists a statistically significant effect of climate change on economic growth in European countries, when economic variables are explicitly taken into account in the estimation. Thus, we want to contribute to the research on the effects of global warming with respect to the economic development of countries.

The rest of the paper is organized as follows. Section two presents the empirical set up, beginning with an overview of the data and models. Further, the various model specifications and regression estimates are provided and discussed in subsections. Section three provides the policy implications and section four, finally, concludes the paper.

2 Empirics and econometric estimations

There exist quite a many empirical contributions analyzing the impact of climate on economic activity and output. A nice survey of approaches can be found in Kolstad and Moore (2020), for example. With this paper we contribute to this strand of literature and estimate in a panel set-up different models using suitable econometric techniques where we allow for climate variables and for classical macroeconomic growth determinants. Since we seek to explore the effect of climate change on economic growth, the growth rate of real GDP per capita is our dependent variable for all our estimations, while the climate variables as well as the standard macroeconomic control variables are the explanatory variables on the right hand side of the regression equations.

We estimated several specifications, the results below refer to the annual, three years and five years growth rate, respectively. This allows to capture a broader perspective on the growth rate, the immediate or short term as well as the medium and long term effect by dividing the whole observation period into sub-periods. We construct overlapping intervals so that the estimations can be done without loosing explanatory power or strength in terms of available observations. Regarding the growth rate G at time t, we consider three different intervals (five years $l = 5$, three years $l = 3$ and one year $l = 1$), that is $y_{i,t} - y_{i,t-l}$ with y denoting the natural logarithm of real GDP per capita, implying that we analyze the question of how the climate variables and the control variables affect the growth rate for the following $l - 1$ years, see Woo and Kumar (2015) or Bökemeier and Geiner (2015) for a similar approach for instance.

2.1 Data overview

We conduct our study for a panel of 24 European countries and refer to annual frequency.[4] The data have been obtained from several established data sources and cover the years from 2002 to 2019. Regarding the weather data, our time series have been taken from the World Bank Climate Change Knowledge Portal (World Bank, 2023). It is ERA5 (reanalysis) data on average air temperatures and average precipitation country-wise. Since the time series should be stationary to avoid spurious estimates we use the growth rate of the temperature in our model as a proxy for the temperature increase due to global warming. Additionally, we use data for precipitation as another climate variable that was obtained by the World Bank Climate Change Knowledge Portal, too. The data for the other macroeconomic variables have been taken from the AMECO homepage (AMECO, 2021), such as the real GDP per capita series for the growth rate, which gives our dependent variable. Regarding the explanatory variables we resorted to the debt to GDP ratio as a fiscal parameter, the trade variables proxied by the "terms of trade" index which represents the ratio of export to imports. The output gap was obtained from AMECO and represents the actual GDP less the potential GDP. The investment effect is taken into account by utilizing the gross fixed capital formation relative to GDP. Inflation is measured by the change in the consumer price index (CPI). The variable "rule of law" is used as the institutional variable and has been obtained from the World Bank Worldwide Government Indicators (World Bank, 2023).

Figure 1 presents the average temperature plot for EU countries between 1970 and 2019. Generally a gradual upward trend can be observed for almost all the countries indicating a slow rise in average temperatures over the chosen time period. Figure 2 depicts the precipitation for the countries in our sample. That variable does not exhibit any particular trend for all countries. In figure 3, we generate country-wise scatter plots to examine the relationship between GDP growth and temperature growth with a linear fit. The relationship is mixed with the data showing a weak negative relationship between GDP growth and temperature growth for some countries such as Finland, Hungary, Italy. On the other hand, there is a weak positive relationship for Belgium, Ireland and Portugal.

[4] Initially we started with 26 economies, however, due to data availability the sample had to be reduced to 24, as there were limited institutional data for the Czech Republic and for Slovakia. Further, the time horizon had to be shortened due to missing observations from the 1990s to our starting point in 2002.

The relationship from the plots is not obvious for most of the countries considered.

Next, we test for stationarity of the variables in order to ensure our estimates do not emanate from spurious regression. Hence, standard panel data unit root tests, the Im, Pesaran and Shi (IPS) and Levin, Lin and Chu test (LLC), are applied to all the variables and the result is reported in table 6 in the appendix.[5] The null hypothesis of both tests is that the series is non-stationary (unit root). From the table it can be seen that there is enough evidence (based on p-values) to reject the null in favour of stationarity for the log of precipitation, for the temperature growth rate, the debt ratio, trade, the output gap, inflation, GDP growth and for the rule of law. In the case of the investment to GDP ratio, the LLC test confirms stationarity.

Figure 4 in the appendix presents a correlation matrix which reveals the correlation coefficients between the variables. The output gap and inflation both have a high positive correlation with GDP growth. Regarding the climate variables, temperature growth has a low positive coefficient with GDP growth whilst precipitation correlates negatively. Rule of law, the debt- and the investment ratio correlate negatively with GDP growth. To further ascertain the impact of all variables on GDP growth, we proceed with panel regressions.

[5]All values in the tables and in figure 4 refer to annual per capita GDP growth rates unless stated otherwise.

Figure 1: Average Temperature for EU countries

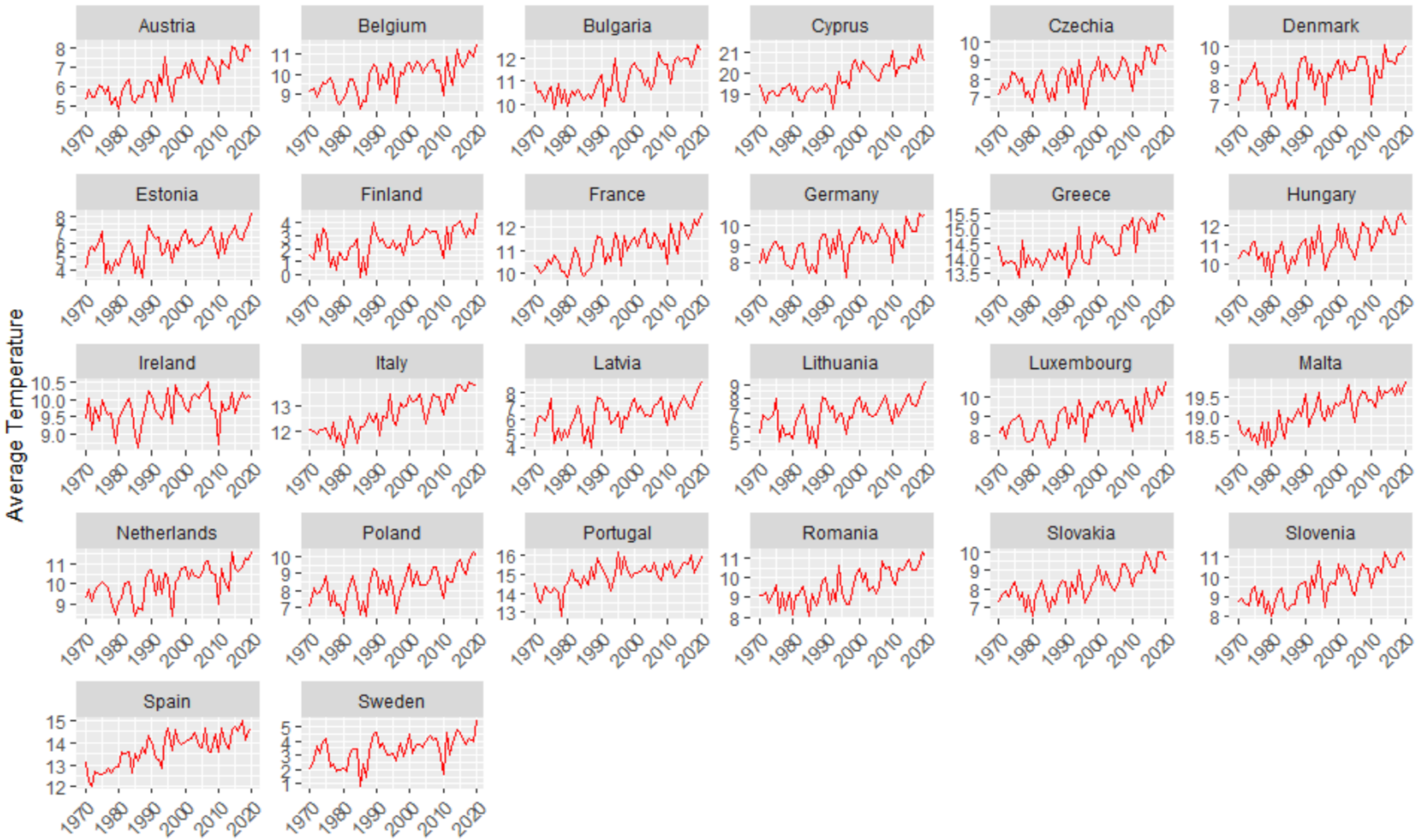


Figure 2: Average Precipitation for EU countries

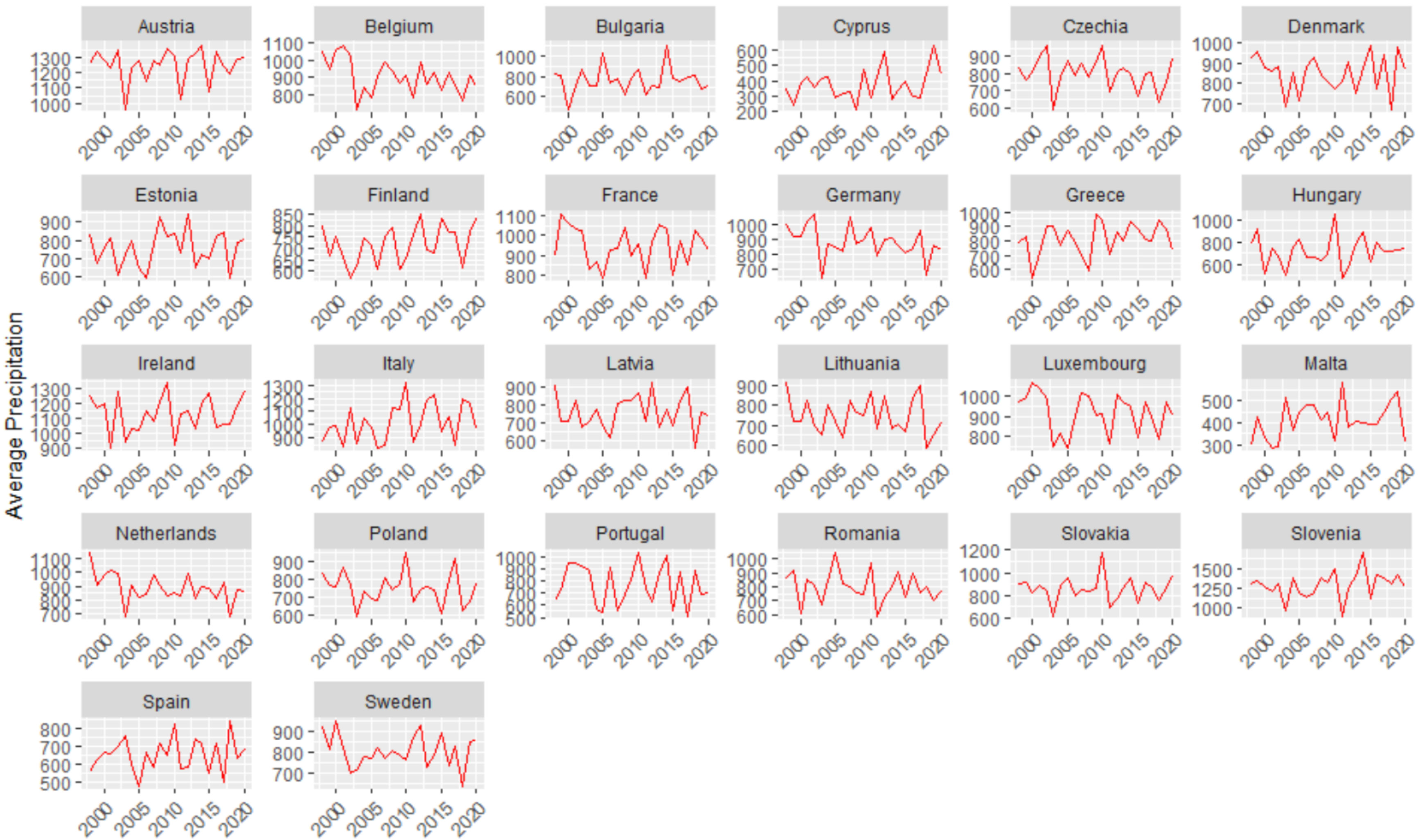
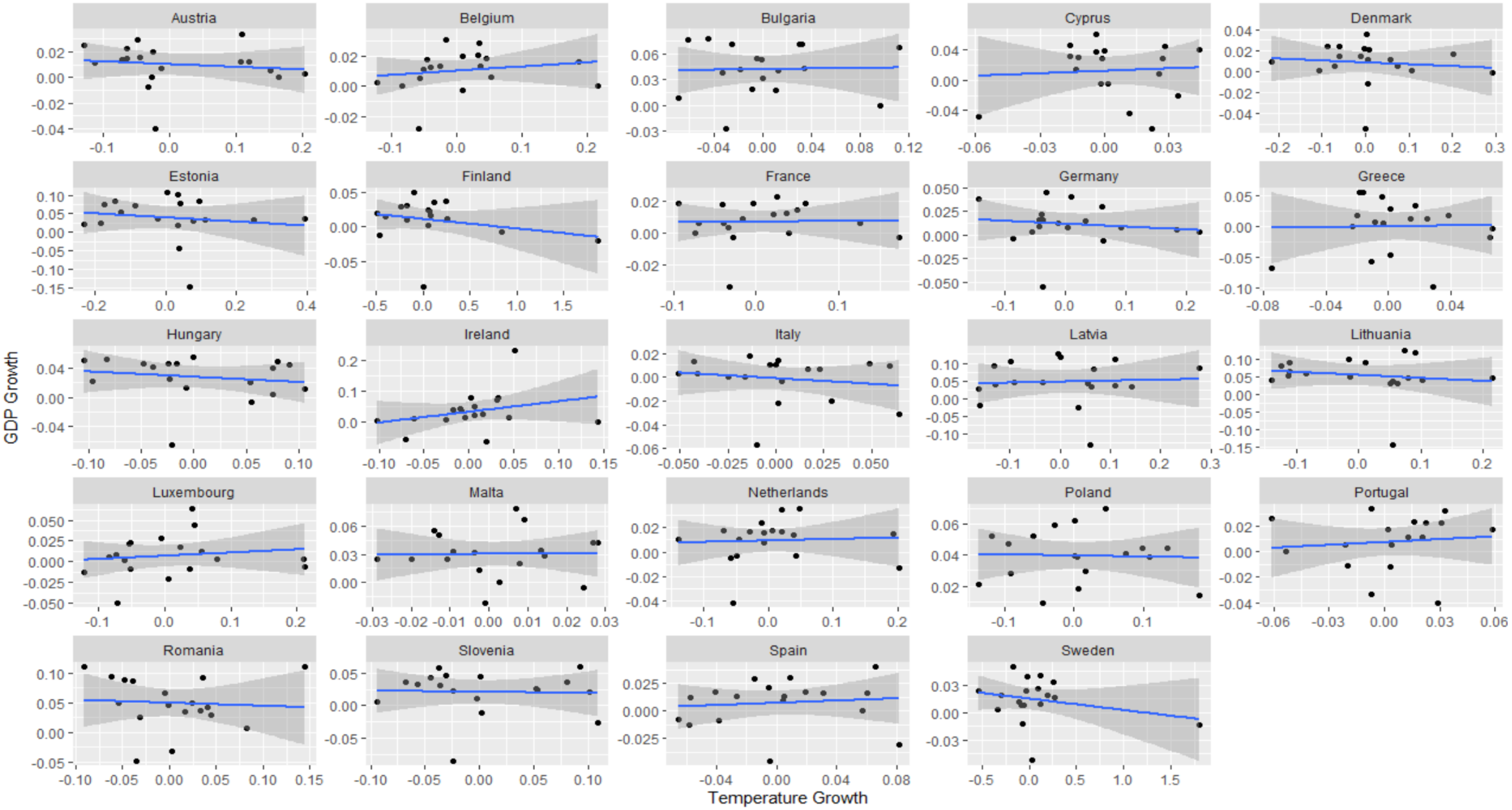


Figure 3: Country-wise scatter plots: Temperature and Economic Growth



Before we proceed with the appropriate econometric model and estimations in the subsequent subsection, we conduct a battery of panel econometric tests to ensure our estimated model is appropriate and sound. To begin with, we specify a panel linear model and test for the presence of individual and time effects in the data (see table 7 in the appendix for the model specification and results of the test). We apply the F-test where a model with nested OLS is compared to a panel fixed effects within estimator. The null hypothesis of the test indicates the absence of the effects (individual, time or both). The result supports appropriateness of the model with both individual and time effects based on the p-values of the resulting hypothesis test which implies the rejection of the null. Hence, we proceed to specify an econometric model that considers both individual and time effects (two-way model). From an economic point, this is justifiable since the time span of our data covers the financial and debt crisis, which affected European economies strongly, so that time effects should not be neglected in the model.

Subsequently, we test for pooling of the model parameters across the cross-section of the panel using the Chow test (based on F-test of stability). This is necessary because the assumption that parameters in a panel data setting can be pooled reflects a stringent restriction which could lead to biased estimates if the pooled model assumption does not hold (see Baltagi, 2021). Regarding the pooling test a restricted model which consists of linear fixed effects with variable intercept (but with identical slope coefficient) is compared to an unrestricted model made up of a panel variable coefficient model (variable intercept and variable slope). The null hypothesis indicates model stability or comparability of both models. The results of the test can be found in the left panel of table 8 (in the appendix designated fixed effects (a)). Results indicate a rejection of a pooled slope parameter based on the p-value of the hypothesis, implying that a model with one homogeneous parameter estimate is not feasible. Next, we explore and account for heterogeneity in the data and construct country dummies based on the temperature growth variable to augment the model. We do this to account for heterogeneity in the model in order to aid pooling of the slope parameter. Based on figure 8, we augment the model with dummy variables for Finland, Sweden and Estonia since these countries have the most variations in temperature growth. The right panel of table 8 (designated fixed effects (b)) depicts the results of the pooling test which fails to reject the null hypothesis of model stability indicating that the augmented model is suitable for pooling. Hence, we proceed with the model specification that consists of a two-ways fixed effects (consisting of individual and time fixed effects) with augmented country dummies.

In what follows, we estimate and discuss three different econometric models examining the relationship between climate change and economic growth. Firstly, we proceed with a panel linear fixed effects model. The results are presented in subsection 2.2. Subsequently, we study a dynamic model with an estimation based on the difference Generalized Methods of Moments (GMM) model, again with individual and time effects, which accounts for possible inertia in the growth rate. These results are presented in subsection 2.3. Finally, we examine the effect of temperature growth directly on GDP growth where we partial out all the effects of the other macroeconomic and institutional variables. The outcomes are shown and discussed in subsection 2.4. The next subsection presents the different model specifications and parameter estimates.

2.2 Panel Linear Specification

In this subsection, we specify and estimate a linear panel fixed effects model to examine the relationship between climate change and economic growth. A model with both individual and time fixed effects is estimated as per the specification below

$$G_{i,t} = \alpha_i + \gamma_t + \beta T_{i,t} + \theta P_{i,t} + \sum_{j=1}^{m} \phi_j CV_{i,t}^{j} + \sum_{h=1}^{3} \gamma_h D_h + U_{i,t} \tag{1}$$

where $i = 1, \ldots, N$, refers to the individual countries in the panel and $t = 1, \ldots, T$, is the time dimension. The variable G denotes the real growth rate of GDP per capita. The coefficient α_i gives the individual effects which are time invariant, whilst γ_t is the time effect. The variables T and P are our covariates of interest which represent the growth rate of the temperature and the log of precipitation, respectively. The variable CV is a vector of control variables made up of macroeconomic variables and an institutional variable as already discussed. The coefficients β, θ and ϕ indicate the impact of the temperature growth, of the precipitation and of the control variables on GDP growth, respectively. D represents the specific country dummies generated from Finland, Sweden and Estonia as discussed in the previous subsection. Finally, U is the error term which is assumed to be uncorrelated, have a zero mean and a constant variance. Equation 1 is estimated with a linear panel within estimator with two way error component model. The standard errors are based on whitening of residuals using Heteroscedasticity and Autocorrelation Consistent (HAC) covariance matrix estimation according to Newey and West (1987) so that they are robust against serial correlation and heteroskedasticity.

Since the countries have geographic and economic link (for instance belonging to an economic union such as the EU), there is a high possibility of spillover effects of policy measures. Moreover, such countries in a monetary union for instance could respond to shocks in a similar way. This could lead to a correlation of residuals and could affect computation of standard errors and, hence, impact on inference. The need to test and account for cross-sectional dependence (CSD) in panel data is, therefore, important. We resort to the Pesaran test (Pesaran, 2004) to test for the presence of cross-sectional dependence in the residuals of the estimated model and provide the results together with the estimates.

Table 1 provides the estimation results for the standard linear panel fixed effects model with individual and time effects. The dependent variable is given by per capita GDP growth rates over three different periods: the annual growth rate in the first part of table 1 (columns 2 to 4), the three years growth rate (columns 5 to 7) in the middle and, finally, the five years growth rate (columns 8 to 10) for the longer run perspective. For each time period the model outcomes are presented step-wise, that is, first including only the environmental variables Mod 1, temperature and precipitation, then adding the macroeconomic effects in specification Mod 2 and, finally, adding the institutional parameter in Mod 3.

For the annual growth rate the table indicates that there is an insignificant relationship between the temperature growth rate and economic growth. This refers to the immediate effect of temperature change. Precipitation does not turn out to exert a significant effect on the economic activity. This holds for all the models Mod 1, Mod 2 and Mod 3. Including the macroeconomic regressors shows that the fiscal position (proxied by lagged debt to GDP ratio) exerts a positive influence on growth in the next period. This seems to be counter-intuitive but might be explained by the fact that we consider the pool of European economies with an average debt ratio of 59.93% (cf. summary statistics in table 5 in the appendix) and the numbers are rather low since countries like Luxembourg and the Baltics are included in the panel, too. The distribution of the values for the percentiles is reported in table 4. For 80% of the observations the debt ratio is below 90% of GDP so that the negative effect of high debt ratios on growth may not yet show up. This is also in line with the literature in part, e.g. Baum et al. (2013) find a positive effect of debt on economic growth for low debt ratio values. In addition, it must be emphasized that this result should be considered with caution. This holds because, as already pointed out in the introduction, the period budget constraint should be taken into account when the effect of a fiscal variable is under consideration. For example, a higher debt ratio of the previous period could be the result of higher deficit financed public investment that raises economic growth. We do not pursue that issue further because our interest does not lie in the question how fiscal policy affects growth, but, in the effects of climate change and the fiscal variable is merely included as a control.

The output gap exerts a positive effect on the growth rate, meaning that economic growth is the higher the smaller the difference between actual and potential output is. In Mod 2 inflation seems to have a slightly positive significant effect on annual growth, while the trade variable, as well as investment did not turn out to be significant. Including the institutional variable does not change the basic results regarding the variables mentioned above. The variable rule of law negatively affects growth which might be explained by too many rules and regulations and a lot of bureaucracy that hampers economic growth. Further, when the number of regulations rises the share of people in rent seeking occupations may go up, too, and slow economic growth. For example, Murphy et al. (1991) found that countries with a high proportion of engineers grow faster whereas economies with a high share of lawyers grow more slowly.

For the medium term, 3 years growth interval, the picture changes regarding the temperature effect. Here, the temperature change exerts a statistically significant positive influence on the economic growth rate (Mod 1). This is in contrast to the insignificant effect obtained for annual growth rates described above. Adding the macroeconomic and institutional variables to the 3 years growth model the effect of the temperature change is no longer statistically significant. The effects of the other explanatory variables are rather similar to the estimation with annual growth rates: precipitation is insignificant, debt exerts a positive effect, the trade coefficient is again insignificant, the output gap and inflation have a positive effect on medium growth, while the rule of law coefficient remains negative. In Mod 3 with both the macroeconomic and institutional variables included the investment coefficient becomes positive and statistically significant. This can be interpreted such that investment and, thus, the accumulation of capital enhances economic growth in the medium term which is in line with the literature.

For our long run set up, the 5 years growth interval in the right part of table 1, the outcomes resemble the findings from the 3 years specification. In Mod 1 the temperature change coefficient turns out to be positive while the other environmental variable, precipitation, is again insignificant throughout all three specifications (Mod 1, Mod 2 and Mod 3). This supports the finding that it is difficult to derive conclusive evidence regarding the effects of climate change on a complex dynamic system such as advanced modern economies that operate with sophisticated technologies. The other coefficients are similar to the three years growth specification and show the expected signs with the interpretation discussed above. Hence, summing up our linear panel fixed effects estimation outcomes it seems that it is difficult to derive conclusive results regarding the relationship between climate change and its consequence for economic activity, here measured in terms of real economic per capita growth.

We estimate an alternative model where we consider the lag of temperature growth (our covariate of interest) in the model specification as shown in table 9 in the appendix. This means that we investigate the effect of the previous period because of a possible lag in the response of the economy to a climatic change. Comparing the estimation results to table 1, it can be noticed that there is no significant difference between both models - pointing to the robustness of our model irrespective of whether we use the immediate temperature growth or the lagged temperature growth.

Table 1: Panel Linear Fixed Effects Model

	1 Year Growth Interval			*3 Year Growth Interval*			*5 Year Growth Interval*		
Variables	*Mod 1*	*Mod 2*	*Mod 3*	*Mod 1*	*Mod 2*	*Mod 3*	*Mod 1*	*Mod 2*	*Mod 3*
Temp growth	0.0047	-0.0059	-0.0060	0.0405***	0.0049	0.0046	0.0414**	-0.0122	-0.0126
	(0.0075)	(0.0054)	(0.0055)	(0.0148)	(0.0126)	(0.0124)	(0.0164)	(0.0135)	(0.0119))
Precipitation	0.0012	-0.0026	-0.0036	-0.0003	-0.0066	-0.0099	0.0078	0.0062	0.0015
	(0.0090)	(0.0068)	(0.0067)	(0.0168)	(0.0068)	(0.0099)	(0.0246)	(.0188)	(0.0164)
Lagged debt ratio		0.0538***	0.0577***		0.1078***	0.1216***		0.0780	0.0976*
		(.0160)	(0.0144)		(0.0407)	(0.0346)		(0.0627)	(0.0533)
Trade		-0.0005	-0.0002		-0.0022	-0.0013		-0.0022	-0.0008
		(0.0004)	(0.0003)		(0.0010)	(0.0008)		(0.0020)	(0.0016)
Output gap		0.0056***	0.0057***		0.0141***	0.0147***		0.0140***	0.0149***
		(0.0007)	(0.0007)		(0.0018)	(0.0014)		(0.0032)	(0.0025)
Inflation		0.0878*	0.0640		0.2208**	0.1373*		0.4047***	0.2867**
		(0.0489)	(0.0503)		(0.0861)	(.0811)		(0.1197)	(0.1220)
Investment ratio		-0.0044	0.0043		0.0344	0.0651**		0.1087	0.1521***
		(.0121)	(0.0100)		(.0382)	(0.0294)		(0.0241)	(0.0545)
Rule of Law			-0.0416***			-0.1465***			-0.2070***
			(0.0092)			(0.0231)			(0.0341)
R^2	0.004	0.340	0.383	0.013	0.509	0.610	0.005	0.399	0.497
Observ	432	432	432	432	432	432	432	432	432
CSD test	0.65(0.514)	-0.78(0.437)	-1.24(0.215)	0.16(0.872)	-0.81(0.416)	-2.05(0.04)	-0.07(0.939)	0.58(0.563)	-0.49(0.625)

Estimation of $G_{i,t} = \alpha_i + \gamma_t + \beta T_{i,t} + \theta P_{i,t} + \sum_{j=1}^{m} \phi CV_{i,t}^{j} + \sum_{h=1}^{3} \gamma_h D_h + U_{i,t}$ using Panel fixed effects. The *, ** and *** indicates statistical significance of 10% , 5% and 1%, respectively. Standard errors are based on HAC estimator, hence they are robust against serial correlation and heteroskedasticity. The Pesaran Cross Sectional Dependence (CSD) test reveals the absence of CSD for all the specifications with the exception of Mod 3 (for 3 year growth interval) which shows a rejection of the null hypothesis of CSD.

2.3 Dynamic panel specification

In a growth context it seems to be appropriate to consider a dynamic set up like a GMM estimation which we will consider in the next step. Among other things, this allows to take into account the current status of development or the inertia of the dependent variable, the growth rate. Hence, we consider a dynamic model specified as follows,

$$G_{i,t} = \alpha_i + \gamma_t + \pi G_{i,t-1} + \beta T_{i,t} + \theta P_{i,t} + \sum_{j=1}^{m} \phi_j CV_{i,t}^{j} + \sum_{h=1}^{3} \gamma_h D_h + U_{i,t} \quad (2)$$

where the lag of the dependent variable ($G_{i,t-1}$) is included on the right hand side of the model and π measures the impact of the inertia of GDP growth. A dynamic model in this form is characterized by the persistence of serial correlation because of the correlation between the error term and the lagged dependent variable (Baltagi, 2021) and, hence, a recipe to account for model endogeneity. We, therefore, apply panel GMM by Arrelano and Bond (1991) where the endogeneity problem is circumvented by using lags of the variables as potential instruments for the model. The validity of the instruments is confirmed by conducting the Sargan test of over-identifying restriction. That is to test if residuals do not correlate with the instruments.

The results for the dynamic GMM model can be found in table 2. The set up of the table, the model distinctions and the growth categories will remain the same to make the results comparable to those from the standard panel model in table 1.

The outcomes of the dynamic panel model, a difference GMM specification with individual and time effects, in table 2 again present mixed results and no clear pattern, particularly as regards the effect of the climatic variable. For the annual growth rate the temperature does not have a significant effect on growth in the next year, also precipitation turns out to be insignificant. As regards the lagged GDP growth rate there is no clear-cut picture, in Mod 1 it is statistically significant and positive, in Mod 2 it is insignificant, in Mod 3 it is statistically significant and negative. For all the other macroeconomic variables in Mod 2 as well as the inclusion of the institutional variable in Mod 3 the effects from the linear fixed effects model are confirmed. The estimations show a positive significant effect of the debt ratio on annual growth and the same holds for the output gap variable, while the other macroeconomic variables do not exert a significant effect. Again, the institutional variable rule of law shows a negative influence on economic growth.

For the medium term specification, 3 years growth, the lagged GDP growth rate shows a significantly positive effect with respect to the growth rate of the following period. This supports the hypothesis of an inertial behavior of economic growth. Regarding the other variables, again just like in the linear fixed effects estimation in table 1, the temperature displays a significant positive relationship with economic growth in the next three years in specification Mod 1. In Mod 2 and Mod 3, however, the effect of the temperature change becomes again statistically insignificant. The other environmental, macroeconomic and institutional variables support the findings from the estimation with annual growth rates: there is a small positive effect of the debt ratio and of the output gap. While the rule of law again exerts a negative effect, the other variables are not statistically significant.

For the last part of table 2 with the 5 years growth rates most estimation results support the 3 years growth results: again, there is inertial behavior of the growth rate that has a positive impact on subsequent growth, a positive significant fiscal effect and a statistically significant positive effect of the output gap. Again, the effect of the institutional variable turns out to be statistically significant and negative. With the 5 years growth specification inflation has a significant positive effect on the economic activity in Mod 2, but, is insignificant in Mod 3, while investment and trade remain insignificant in both models. And, as in the linear fixed effects estimation above, regarding the environmental variables temperature change is only significantly positive in specification Mod 1 and precipitation exerts no significant effect on economic growth.

Resuming these findings demonstrates again that there does not exist a clear-cut relationship between economic growth and climate change. Whereas our estimations reveal no significant growth effect in the short run, the effect becomes insignificant or even positive in the long run and in the medium run, respectively. We should like to add that initially we included different specifications of a variable capturing the initial level of real GDP per capita, however, those did not turn out to be significant so that we decided to run the regressions without that variable. Outcomes on these estimations are available on request.

Furthermore, we estimate a similar model, however, with lagged temperature growth as the covariate of interest (depicted in table 10 in the appendix). The results do not differ from our main estimates in table 2. None of the environmental variables exerts a statistically significant effect on economic growth and, hence, confirm that the estimates are quite robust, irrespective of whether we use the immediate effect of temperature growth or the lag of temperature growth.

We report the results of the Sargan test of overidentifying restriction. Based on the p-values, the null hypothesis which indicates validity of our instruments, cannot be rejected pointing to the fact that our instruments are valid. Additionally, the Arellano-Bond second order autocorrelation test which reveals the absence of autocorrelation based on the p-values is reported in the table. The p-values imply a non-rejection of the null hypothesis of no autocorrelation for all model specifications. Finally, we inspect the residuals of our dynamic models for evidence of cross sectional dependence (CSD) which may distort the standard errors and, hence, affect inference in our models. We plot the country-wise residuals for all the model specifications and show in figure 5, figure 6, and figure 7 that the residual for each country is unique and does not exhibit a resemblance between countries. Hence, we argue that there is not an evidence for CSD in the residuals.

Table 2: Dynamic Panel Model Estimation

	1 Year Growth Interval			3 Year Growth Interval			5 Year Growth Interval		
Variables	*Mod 1*	*Mod 2*	*Mod 3*	*Mod 1*	*Mod 2*	*Mod 3*	*Mod 1*	*Mod 2*	*Mod 3*
Lagged GDP Growth	0.2001**	-0.0226	-0.1019**	0.6719***	0.4747***	0.3769***	0.8145***	0.7207***	0.6567***
	(0.0800)	(0.0568)	(0.0487)	(0.0282)	(0.0537)	(0.0531)	(0.0351)	(0.0504)	(0.0359)
Temp growth	0.0003	-0.0048	-0.0030	0.0240**	0.0095	0.0100	0.0239*	0.0044	0.0032
	(0.0064)	(0.0044)	(0.0046)	(0.0116)	(0.0088)	(0.0107)	(0.0127)	(0.0067)	(0.0069))
Precipitation	0.0023	0.0010	-0.0032	-0.0042	-0.0025	-0.0106	-0.0221	-0.0138	-0.0183
	(0.0112)	(0.0073)	(0.0065)	(0.0150)	(0.0103)	(0.0092)	(0.0213)	(0.0152)	(0.0137)
Lagged debt ratio		0.1053***	0.0904***		0.1598***	0.1347***		0.1256***	0.1036***
		(0.0181)	(0.0155)		(0.0276)	(0.0219)		(0.0251)	(0.0251)
Trade		-0.0004	-0.00001		-0.0014	-0.0008		-0.0023	-0.0015
		(0.0005)	(0.00001)		(0.0009)	(0.0008)		(0.0013)	(0.0011)
Output gap		0.0052***	0.0061***		0.0095***	0.0113***		0.0102***	0.0111***
		(0.0008)	(0.0008)		(0.0022)	(0.0019)		(0.0024)	(0.0019)
Inflation		0.0657	0.0680		0.0630	0.0490		0.1270**	0.1200
		(0.0548)	(0.0564)		(0.0738)	(0.0696)		(0.0645)	(0.0720)
Investment ratio		0.0103	0.0106		0.0295	0.0377		0.0103	0.0285
		(0.0165)	(0.0159)		(0.0343)	(0.0321)		(0.0406)	(0.0374)
Rule of Law			-0.0502***			-0.1148***			-0.1237***
			(0.0135)			(0.0296)			(0.0268)
Observ	384	384	384	384	384	384	384	384	384
Sargen Test	24(0.99)	24(0.99)	24(0.99)	24(0.99)	24(0.99)	24(0.99)	24(0.99)	24(0.99)	24(0.99)
Autoc test	-0.9(0.323)	-0.7(0.471)	-0.8(0.437)	-0.7(0.500)	0.5(0.647)	0.3(0.758)	-1.8(0.079)	-1.6(0.113)	-1.6(0.113)
Wald test of coefficients	24.4(0.000)	203.2(0.00)	393.5(0.000)	866.3(0.000)	6782.9(0.000)	4897.8(0.000)	947.8(0.000)	1815.7(0.000)	2899.5(0.000)

Estimation of $G_{i,t} = \alpha_i + \gamma_t + \pi G_{i,t-1} + \beta T_{i,t} + \theta P_{i,t} + \sum_{j=1}^{m} \phi_j CV_{i,t}^{j} + \sum_{h=1}^{3} \gamma_h D_h + U_{i,t}$ using difference GMM. The *, ** and *** indicates statistical significance of 10% , 5% and 1%, respectively. The instruments used consists of 2 to 10 lags of temperature growth, precipitation, debt to GDP ratio, Net export, output gap, inflation and rule of law.

2.4 Partialling out the effects of control variables - Application of the Frisch-Waugh-Lovell theorem

In what follows, we deem it significant to study the relationship between only economic growth and the change in temperature since precipitation has been found to be insignificant in all previous estimations. Therefore, we estimate the effect of a change in temperature on economic growth whilst we control for the effect of the other macroeconomic and institutional variables. We empirically apply the Fisch-Waugh-Lovell (FWL) theorem (see Lovell, 2008, and Frisch and Waugh, 1933) for causal inference which entails partialling out the effect of all the control variables when estimating the effect of climate change on economic growth. The aim is to isolate the effect of the control variables on the variables of interest so that we are able to examine the effect of only the change in temperature on economic growth. This simplifies the final model estimation and enables us to obtain the true relationship between the variables with simple interpretability. We implement a two step procedure as follows: in the first step we use panel GMM (Arrelano and Bond estimator) to partial out the effect of all control variables on GDP growth and on temperature growth, in a second step we regress the residuals from the regression of growth on control variables on the residuals obtained from the regression of the temperature change on the control variables.

The first specification where we regress growth on the control variables looks as follows,

$$G_{i,t} = \alpha_i + \gamma_t + \pi G_{i,t-1} + \theta P_{i,t} + \sum_{j=1}^{m} \phi CV_{i,t}^{j} + \sum_{h=1}^{3} \gamma_h D_h + U_{i,t} \tag{3}$$

The justification for using panel GMM for the first step is due to possible inertia of the dependent variable, the growth rate. Equation (3) depicts a regression of the GDP growth rate on all control variables with the exception of temperature growth. The residual recovered is depicted by $\tilde{G}_{i,t}$. Similarly, we partial out the effect of all control variables on temperature growth with the omission of GDP growth rate in the following regression,

$$T_{i,t} = \alpha_i + \gamma_t + \pi T_{i,t-1} + \theta P_{i,t} + \sum_{j=1}^{m} \phi CV_{i,t}^{j} + \sum_{h=1}^{3} \gamma_h D_h + U_{i,t} \tag{4}$$

Once again we use panel GMM to estimate specification (4) and recover the residuals we denote by $\tilde{T}_{it}$. In the second final step, we regress the GDP growth residuals on the temperature growth residuals in order to obtain the effect of the change in temperature on economic growth using panel fixed effects estimation with the following specification,

$$\tilde{G}_{i,t} = \tilde{T}_{it} + noise_{i,t} \tag{5}$$

The use of the panel fixed effects estimation in the second step is justified by the fact that the inertia of the growth variables has been partialled out. Hence, we proceed with a standard linear fixed effects model for the estimation.

Table 3 presents the output after the two step partialling out procedure according to the FWL theorem. Again, a mixed result can be observed from the table. Using GDP growth with 1 year growth intervals as the dependent variable in the first step procedure, we obtain a negative significant effect of temperature growth on economic growth. However, a 3 year GDP growth interval shows an insignificant relationship. Similarly, a five year growth interval does not yield a significant effect of the change in temperature on economic growth.

Table 3: Estimation - FWL Approach

	Response variable: GDP Growth		
Variable	*1 Year Interval*	*3 Year Interval*	*5 Year Interval*
Resid (Temp growth)	-0.0135***	0.0011	-0.0058
	(0.0044)	(0.0049)	(0.0055)
Observ	384	384	384
First step procedure	GMM	GMM	GMM
Second step procedure	Fixed effect	Fixed effects	Fixed effects
Individual fixed effects	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes

Furthermore, we estimate a similar model with the lagged temperature growth as the covariate of interest (depicted in table 11 in the appendix). Qualitatively, the results are identical to those in table 3, except for the effect of the temperature change on annual growth that is no longer statistically significant. Thus, none of the environmental variables seems to exert a significant effect on economic growth and, hence, confirm that the estimates do not reveal a clear-cut effect of temperature change on economic growth.

3 Policy implications

Our empirical estimations did not yield a clear-cut effect of a rising temperature on economic growth in European economies. Only for the case of annual growth rates in the FWL setting we found a statistically significant negative effect of a higher temperature growth on economic growth, whereas in the case of 3-year and 5-year growth rates that effect was statistically insignificant or even significantly positive. Hence, there is no robust empirical evidence that climate change, proxied by a higher temperature, negatively affects the economic evolution of the European economies in our sample. Consequently, from this perspective it is hard to justify costly policy measures aiming to reduce greenhouse gas emissions in the EU. That holds because those policies go along with tremendous costs implying a loss of welfare according to the Kaldor-Hicks criterion.

Further, as pointed out in the introduction there exists great model uncertainty as regards the effects of GHGs. But, nevertheless, it cannot be excluded that the continued rise of the GHG concentration will go along with rising damages and catastrophic events cannot be excluded either, even if the empirical evidence up to now is small. Hence, due to the precautionary motive it is justified to reduce those emissions. However, unilateral measures undertaken in order to cut GHG emissions of EU countries do not affect the climate on earth since the share of EU emissions relative to world-wide emissions is too small to have a significant impact. Only if the world cooperated these measures would be reasonable. But, in particular developing economies put more emphasis on economic growth than on environmental concerns. Thus, the Chinese president announced that China alone determines how fast it tackles the challenge of climate change and its decisions will not be influenced by other countries (see Shepherd et al., 2023). The G20 countries announced that they intend to support the production of "clean" energies, but, they could not agree to phase out fossil fuels (cf. Arasu, 2023). Russia declared that it will oppose any plans to stop the use of fossil fuels in principle (cf. Mooney und Williams, 2023). Therefore, it is to be expected that the GHG concentration will continue to rise, independent of any measures taken by EU countries.

Given that, it is even more doubtful that the costs of reducing GHG emissions amounting to trillions of euros in Europe yield welfare gains. This holds because the resources spent, although formally investments, do not necessarily raise the productive capital stock and, consequently, not production possibilities in the future. Hence, not only the current generation looses but future generations, too, since they cannot profit from higher production possibilities in the future. A paradoxical situation arises: Policy measures aiming to preserve the well-being of future generations make them worse off because, on the one hand, they do not affect the climate on earth and, on the other hand, they do not lead to a higher productive capital stock and to an extension of production possibilities. Future generations in Europe will be confronted with great challenges since they will have to cope with quite a many problems such as an increase in the percentage of elderly people, the lack of a qualified workforce, high government debt and possibly necessary measures to adapt to the climate change, just to mention a few. Only if they dispose of sufficient economic and technical means they can meet those challenges.

These considerations demonstrate that it is difficult to justify the net zero goal of the European Green Deal (see https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en) that intends to reduce net GHG emissions in the EU to zero by 2050 from an economic point of view. However, going beyond pure economics and accepting that it is mankind's task to preserve the earth from a moral-ethical responsibility, the net zero position could be justified. But even then, the welfare of current and future generations should be taken into account. Considering this the EU net zero goal as a final goal is to be seen sceptical since it implies that this goal serves as an end in itself rather than an intermediate goal that is pursued in order to maximize welfare of the population in the EU. This holds all the more as there exists great model uncertainty with regard to the economic and ecological effects of GHGs, as already pointed out above.

4 Conclusion

In this paper we applied modern panel estimation techniques to empirically analyze the relationship that exists between economic per capita growth and climatic variables allowing for macroeconomic and institutional variables as controls. We did so for 24 European countries from 2002 to 2019. Our empirical estimations did not yield a robust relationship between climate change, proxied by the temperature increase, and economic growth. Further, the climate of the earth is an extremely complex system and there exists a high degree of model uncertainty that is reflected by the partly poor performance of many of the climate models, despite their high degree of sophistication and complexity.

Given those uncertainties policy measures aiming to reduce GHG emissions can only be justified by the precautionary motive, from an economic point of view, since drastic effects resulting from a further rise of the GHG concentration cannot be excluded. However, unilateral GHG reductions in the EU do not affect the climate of the earth. Further, investments that do not raise the aggregate capital stock but only lower GHG emissions imply stagnating production possibilities making future generations of Europeans worse off due to the many challenges they will have to face. Therefore, the net zero goal of the EU Green Deal is to be seen critical from a welfare theoretic perspective since it is set as a final goal serving as an end in itself instead of maximizing welfare.

In our analysis we did not allow for heterogeneity in the data, meaning that the effects of climatic change may turn out different depending on which economies or regions are considered. In addition, it could be interesting to analyze whether there exist several regimes that are characterized by different relations between the temperature change and growth, as in the case of public debt policies (see e.g. Owusu et al., 2023). This is left for future research that could explore these issues further.

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Appendix

Table 4: Percentiles for selected variables

Variable	10%	25%	50%	75%	80%	90%
GDP Growth rate	-1.34	0.49	1.83	3.95	4.37	6.12
Temperature	6.02	8.21	10.33	12.59	13.80	15.45
Debt-GDP-ratio	15.94	36.80	55.35	78.73	87.80	105.50

Table 5: Summary Statistics

Statistic	Mean	Minimum	Maximum	Std. Dev
Precipitation	6.67	5.37	7.44	0.30
Rule Law	1.16	-0.27	2.12	0.61
log(Investment ratio)	3.48	-0.22	6.60	1.61
Inflation	2.22	-15.79	25.38	0.03
Output gap	-0.38	-18.30	11.6	3.68
Trade	98.45	66.30	112.10	4.44
Debt to GDP	59.93	3.80	186.40	35.6
Temp growth	1.09	-53.45	186.16	0.16
GDP growth	2.06	-14.67	23.35	0.04

Figure 4: Correlation plot

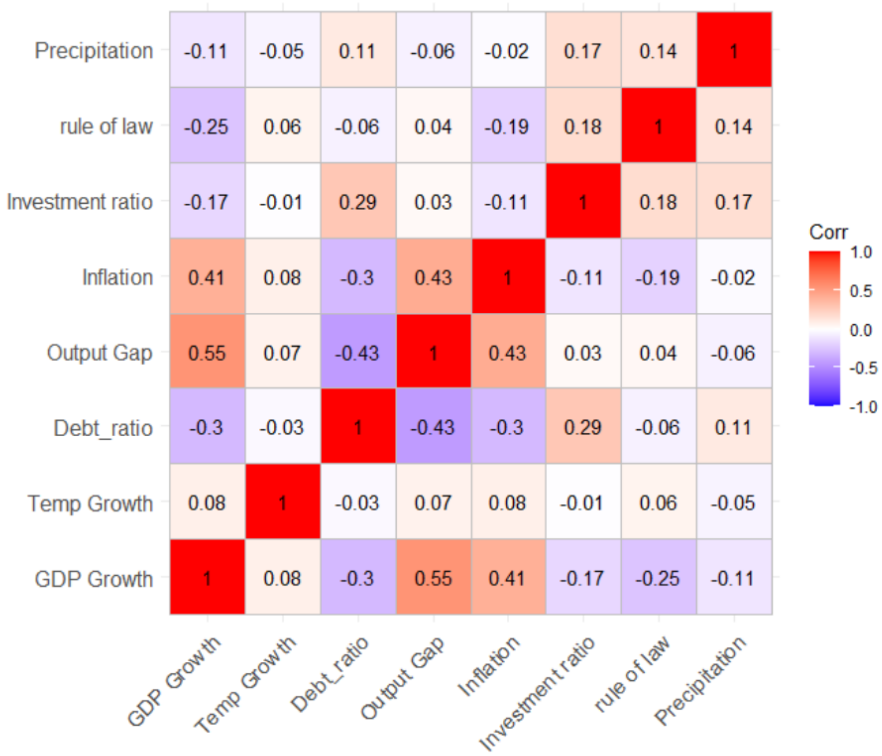

Table 6: Panel Unit Root Test

	Im Pesaran and Shin Test		***Levin Lin and Chu Test***	
Variables	Test Stat	p-value	Test Stat	p-value
Precipitation	-18.083***	0.000	-18.665***	0.000
Temp growth	-24.861***	0.000	-21.127***	0.000
Debt to GDP	-1.414*	0.079	-3.26***	0.001
Output gap	-6.01***	0.000	-5.44***	0.000
Investment ratio	-0.62	0.266	-2.024**	0.022
Inflation	-7.12***	0.000	-7.18***	0.000
Trade	-2.584***	0.005	-4.232***	0.000
GDP growth	-8.86***	0.000	-9.17	0.000
Rule of law	-3.97***	0.000	-3.17***	0.001

Table 7: Testing for individual and time effects - Full sample

	Time effects			***Individual effects***			***Individual and time effects***		
Variables	Test-stats.	P-value	Df1 Df2	Test-stats	P-value	Df1 Df2	Test-stats	P-value	Df1 Df2
Values	9.683	0.000	16 406	6.141	0.000	23 399	9.353	0.000	39 383
Num Obs	432			432			432		

F-Test for Individual and or Time Effects. The null hypothesis indicates the absence of significant effect (for individual, time or both effects)

Table 8: Panel poolability test - Full sample

	Fixed effects (a) and Pvcm				***Fixed effects(b) and Pvcm***			
Variables	F-stats.	P-value	Df1	Df2	F-stats	P-value	Df1	Df2
Values	2.453	0.000	185	216	1.122	0.223	253	144
Num Obs	432				432			

Chow test for poolability of panel data. Fixed effect within model and pooled panel model are compared to Panel Variable Coefficient Model (pvcm). Null hypothesis states model stability and hence comparability of mdels. Alternative hypothesis implies model instability. The estimated model is as follows $G_{i,t} = \alpha_i + \gamma_t + \beta T_{i,t} + \theta P_{i,t} + \sum_{j=1}^{m} \phi CV_{i,t}^{j} + U_{i,t}$, where the dependent variable represents economic growth, the right hand side variables includes the laggeddebt temerature growth, log of precipitation and a set of control variables represent by the vector notation CY_{it}^{j}. To aid poolability the model is augmented with a set of Country dummies (according to climate variables) namely: Finland, Sweden and Estonia.

Table 9: Panel Linear Fixed Effects Model (with lagged temperature growth)

	1 Year Growth Interval			*3 Year Growth Interval*			*5 Year Growth Interval*		
Variables	*Mod 1*	*Mod 2*	*Mod 3*	*Mod 1*	*Mod 2*	*Mod 3*	*Mod 1*	*Mod 2*	*Mod 3*
Lagged Temp growth	-0.0006	-0.0157	-0.0111	0.0869*	0.0267	0.0430	0.1001*	0.0016	0.0245
	(0.0219)	(0.0197)	(0.0196)	(0.0482)	(0.0303)	(0.0273)	(0.0570)	(0.0451)	(0.0429))
Precipitation	0.0014	-0.0029	-0.0039	0.0018	-0.0063	-0.0095	0.0102	0.0058	0.0013
	(0.0090)	(0.0067)	(0.0075)	(0.0171)	(0.0114)	(0.0099)	(0.0247)	(0.0188)	(0.0165)
Lagged debt ratio		0.0538***	0.0577***		0.1078***	0.1218***		0.0783	0.0980*
		(0.0160)	(0.0106)		(0.0407)	(0.0345)		(0.0627)	(0.0534)
Trade		-0.0005	-0.0002		-0.0022**	-0.0012		-0.0021*	-0.0008
		(0.0003)	(0.0003)		(0.0010)	(0.0008)		(0.0019)	(0.0016)
Output gap		0.0055***	0.0057***		0.0141***	0.0147***		0.0140***	0.0148***
		(0.0008)	(0.0004)		(0.0018)	(0.0014)		(0.0033)	(0.0025)
Inflation		0.0859*	0.0621*		0.2221**	0.1375*		0.4003***	0.28128**
		(0.0482)	(0.0372)		(0.0856)	(0.0811)		(0.1353)	(0.1210)
Investment ratio		-0.0043	0.0043		0.0340	0.0646**		0.1085	0.1517***
		(0.0119)	(0.0076)		(0.0384)	(0.0296)		(0.0671)	(0.0544)
Rule of Law			-0.0414***			-0.1473***			-0.2074***
			(0.0081)			(0.0230)			(0.0342)
R^2	0.004	0.340	0.379	0.011	0.508	0.612	0.005	0.399	0.497
Observ	432	432	432	432	432	432	432	432	432
CSD test	0.65(0.517)	-0.84(0.413)	-1.22(0.224)	0.25(0.802)	-0.76(0.446)	-2.08(0.037)	0.11(0.909)	0.50(0.615)	-0.59(0.553)

Estimation of $G_{i,t} = \alpha_i + \gamma_t + \beta T_{i,t} + \theta P_{i,t} + \sum_{j=1}^{m} \phi CV_{i,t}^{j} + \sum_{h=1}^{3} \gamma_h D_h + U_{i,t}$ using Panel fixed effects. The *, ** and *** indicates statistical significance of 10% , 5% and 1%, respectively. Standard errors are based on HAC estimator, hence they are robust against serial correlation and heteroskedasticity.

Table 10: Dynamic Panel Model (with lagged temperature growth)

	1 Year Growth Interval			*3 Year Growth Interval*			*5 Year Growth Interval*		
Variables	*Mod 1*	*Mod 2*	*Mod 3*	*Mod 1*	*Mod 2*	*Mod 3*	*Mod 1*	*Mod 2*	*Mod 3*
Lagged GDP Growth	0.1990**	-0.0322	-0.1042**	0.6713***	0.4697***	0.3746***	0.8140***	0.7200***	0.6566***
	(0.0778)	(0.0553)	(0.0474)	(0.0285)	(0.0540)	(0.0531)	(0.0350)	(0.0519)	(0.0362)
Lagged Temp growth	-0.0019	-0.0067	-0.0057	0.0489	0.0299	0.0355	0.0005	-0.0116	-0.0021
	(0.0206)	(0.0135)	(0.0131)	(0.0316)	(0.0273)	(0.0254)	(0.0304)	(0.0190)	(0.0203))
Precipitation	0.0026	0.00240	-0.0030	-0.0024	0.0004	-0.0103	-0.0205	-0.0170	-0.0180
	(0.0111)	(0.0057)	(0.0065)	(0.0156)	(0.0110)	(0.0095)	(0.0211)	(0.0171)	(0.0137)
Lagged debt ratio		0.1070***	0.0505***		0.1634***	0.1353***		0.1281***	0.1035***
		(0.0185)	(0.01552)		(0.0289)	(.0219)		(0.0266)	(0.0248)
Trade		-0.0004	-0.00002		-0.0014	-0.0008		-0.0022	-0.0015
		(0.0005)	(0.0005)		(0.0009)	(0.0008)		(0.0012)	(0.0011)
Output gap		0.0053***	0.0060***		0.0096***	0.0113***		0.0101***	0.0111***
		(0.0009)	(0.0008)		(0.0025)	(0.0019)		(0.0024)	(0.0019)
Inflation		0.0619	0.0668		0.0612	0.0519		0.1598**	0.1210*
		(0.0544)	(0.0567)		(0.0738)	(0.0705)		(0.0728)	(0.0731)
Investment ratio		0.0111	0.0106		0.0313	0.0377		0.0091	0.0286
		(0.0163)	(0.0159)		(0.0347)	(0.0325)		(0.0403)	(0.0374)
Rule of Law			-0.0501***			-0.1157***			-0.1234***
			(0.0150)			(0.0296)			(0.0268)
Observ	384	384	384	384	384	384	384	384	384
Sargen Test	24(0.99)	24(0.99)	24(0.99)	24(0.99)	24(0.99)	24(0.99)	24(0.99)	24(0.99)	24(0.99)
Autoc test	-0.9(0.381)	-0.6(0.535)	-0.7(0.495)	-0.8(0.42)	0.4(0.706)	0.2(0.839)	-1.8(0.059)	-1.5(0.142)	-1.5(0.142)
Wald test of coefficients	24.06(0.000)	252.2(0.00)	217.3(0.000)	1073.9(0.000)	4353.5(0.000)	4199.4(0.000)	1072.3(0.000)	1770.3(0.000)	2128.5(0.000)

Estimation of $G_{i,t} = \alpha_i + \gamma_t + \pi G_{i,t-1} + \beta T_{i,t} + \theta P_{i,t} + \sum_{j=1}^{m} \phi_j CV_{i,t}^{j} + \sum_{h=1}^{3} \gamma_h D_h + U_{i,t}$ using difference GMM. The *, ** and *** indicates statistical significance of 10% , 5% and 1%, respectively. The instruments used consists of 2 to 10 lags of temperature growth, precipitation, debt to GDP ratio, Net export, output gap, inflation and rule of law.

Table 11: Estimation - FWL Approach (with lagged temperature growth)

	Response variable: GDP Growth		
Variable	*1 Year Interval*	*3 Year Interval*	*5 Year Interval*
Resid (Lagged Temp growth)	0.0006	0.0301	0.0038
	(0.0178)	(0.0211)	(0.0294)
Observ	384	384	384
First step procedure	GMM	GMM	GMM
Second step procedure	Fixed effect	Fixed effects	Fixed effects
Individual fixed effects	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes

Figure 5: Residual plot - GMM model with 1 year growth interval

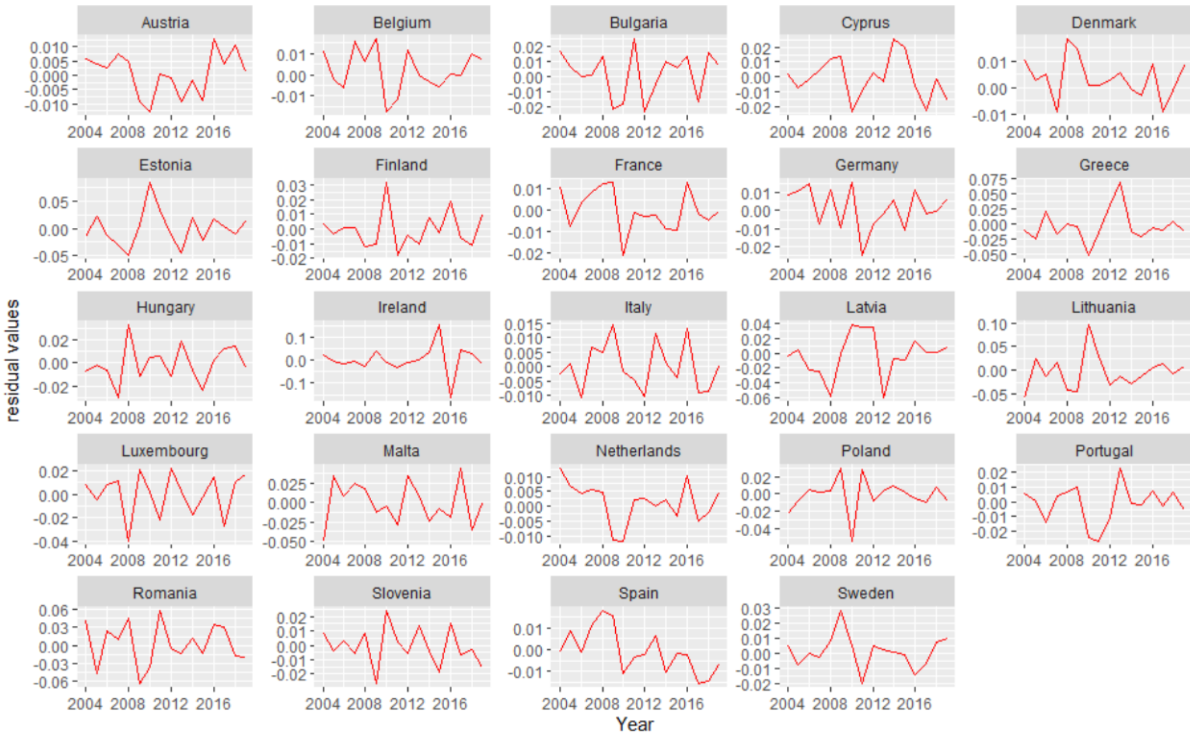

Figure 6: Residual plot - GMM model with 3 year growth interval

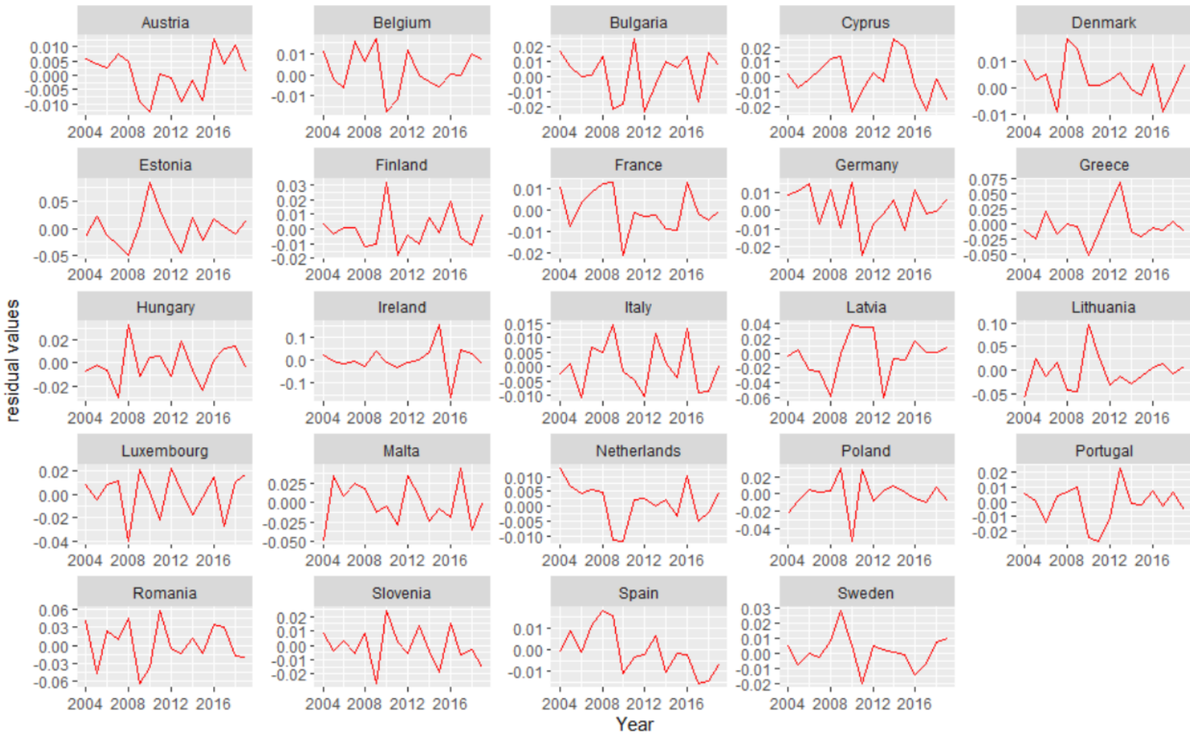

Figure 7: Residual plot - GMM model with 5 year growth interval

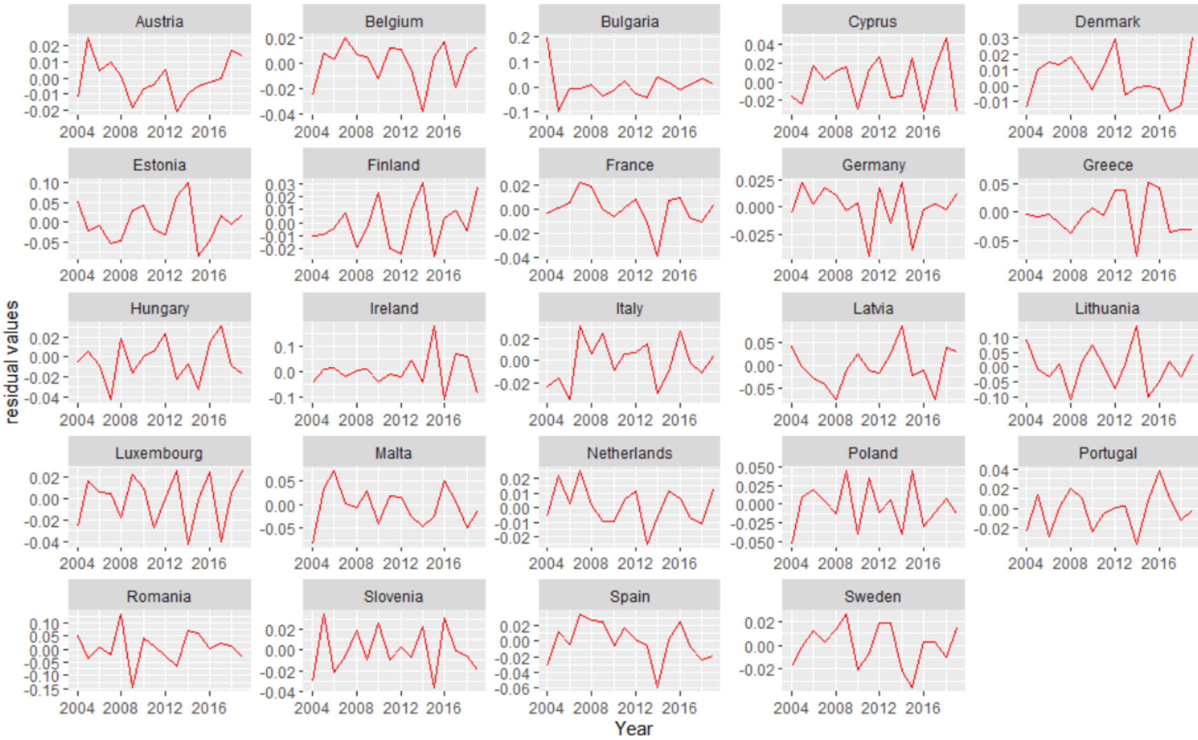

Figure 8: Temperature growth heterogeneity across countries