Stockholm School of Economics

Department of Economics

BE551 Degree Project in Economics

Fall 2022

Weather and Firm Production in Europe

Weather or NUT European Firms are Feeling the Heat

Hanna Johansson (25001) and Leo Ljunggren (25172)

Abstract: With exceeding risks of climate change damages, the economical implications of changes in weather patterns for firm production have become increasingly important. Up until now, a European setting and more time relevant data have been missing in current research analyzing such implications, which is where this thesis resolves such shortcomings. Using the classical Cobb-Douglas production function, a bin approach, and NUTS 2 regions, the implications of weather fluctuations, in terms of daily max temperature and daily accumulated precipitation, on European firm's production were examined. The findings conclude that Europe's output decreases, on average, by 0.266% for each additional day above 30°C, relative to 15-20°C, corresponding to losses of 116 Million Euros in 2010 values. As for precipitation, an average output loss of 0.039%, corresponding to 17 Million Euros in 2010 values, is derived from each additional dry day relative to a day with precipitation level of up to 10 mm. An analysis of heterogeneous treatment effects showed distinctive differences across subregions within Europe, mainly driven by capital and labor factor sensitivities.

Keywords: Climate change, weather, firm production, Europe, Nomenclature of Territorial Units for Statistics (NUTS).

JEL: Q500, Q510, D220, D240, E230.

Supervisor:	Sampreet Goraya
Date submitted:	12.05.2022
Date examined:	12.19.2022
Discussants:	Kasper With & Zeshan Shiekh
Examiner:	Johanna Wallenius

Table of Contents

1. Introduction **3**
- 1.1. Background 4
  - 1.1.1. Long-term Climate 5
  - 1.1.2. Short-term Weather 6
- 1.2. Literature Review 7
  - 1.2.1. Temperature 7
  - 1.2.2. Precipitation 8
- 1.3. Our Contributions 9
- 1.4. Research Questions 10
- 1.5. Thesis Outline 10

2. Methodology **10**
- 2.1. Theoretical Framework 10
- 2.2. Empirical Method 12
- 2.3. Data 17
  - 2.3.1. Method of Data Collection 17
  - 2.3.2. Data Description 18
  - 2.3.3. Summary Statistics 18
- 2.4. Remarks 20
  - 2.4.1. Statistical Remarks 20
  - 2.4.2. Assumptions 21
- 2.5. Model Specifications 22

3. Findings **24**
- 3.1. Temperature 25
- 3.2. Precipitation 27
- 3.3. Lagged Weather 29
- 3.4. Implications of Results 30
- 3.5. Future Impact 31
- 3.6. Conclusions 34

4. Summary **35**

5. References **36**

6. Appendix A - Figures **39**

7. Appendix B - NUTS 2 Regions **50**

1. Introduction

The phenomena of climate change has been an exceedingly pernicious predicament and the consequences are becoming increasingly apparent. In recent years, there has been a swelling rate of extreme weather events,[1] such as heat waves and floods, across the globe in the wake of climate change escalation and global warming intensification.[2] Although many of these calamities are taking place outside of the European region, Europe is in no way spared. In 2022 alone, severe heat waves killed numerous people in France, Italy, and Greece,[3] and during 1980-2020, more than 138,000 people died in the EU due to climate-related extreme weather.[4] In 2022, wildfires in France, Italy, Spain, Greece, and Portugal have displaced thousands,[5] and is becoming increasingly customary in the once untouched subregions of Central and Northern Europe.[6]

The year 2020 was recorded as the hottest year ever in Europe and the Mediterranean region has experienced a 22% increase in rainfall intensity over the last 50 years.[7] The investments required to cover transitional costs to climate friendly alternatives are likewise escalating as the deadlines and goals set out by the Paris Agreement become evermore pressing.[8] Further understanding of the implications of climate change, both on an economic and a humanitarian level, is imperative to be able to curtail this calamitous force. Action is a necessity, not only through government interjection, but from individuals, financial investors, and firms alike.

The costs and economic losses associated with climate change and its consequences could be argued to be a well-needed eye-opening driver for global reform. However, these climate impressions are not ubiquitous and fluctuate extensively, where the poorest regions are generally the ones hit the hardest while simultaneously being the least equipped to cope with such ramifications.[9]

Europe has and is still suffering significant economic losses as a result of climate change. Climate-related extremes between 1980 and 2020 are estimated to have caused economic losses upwards of EUR 487 Billion in the EU-27 member states and close to EUR 509 Billion in the EEA-32 region. Countries like Germany, France, Italy, Switzerland, and Slovenia have suffered the most per capita from these losses.[10] Europe and European firms urgently need to mitigate

[1] Definition of extreme weather events: Occurrences of unusually severe weather or climate conditions. Such events include heat waves, wildfires, freezes, heavy downpours, tornadoes, tropical cyclones, droughts, and floods.

[2] Rosamund Pearce, et al. 2022. "Mapped: How climate change affects extreme weather around the world." Carbon Brief. Accessed on 2 November 2022.

[3] Giovanna Coi, et al. 2021. "The death toll of Europe's heat wave." Politico. Accessed on September 22 2022.

[4] The Council of the European Union. 2022. "Infographic - Climate change costs lives and money." The European Union. Accessed on November 30 2022.

[5] UN Environment Programme. 2022. "As heatwaves blanket Europe, cities turn to nature for solutions." The United Nations. Accessed on October 23 2022.

[6] The Council of the European Union - "Infographic - Climate change costs lives and money."

[7] The Council of the European Union - "Infographic - Climate change costs lives and money."

[8] The United Nations. 2022. "For a livable climate: Net-zero commitments must be backed by credible action." Accessed on October 24 2022.

[9] Mercy Corps. 2021. "The facts: How climate change affects people living in poverty." Accessed on October 22 2022.

[10] European Environment Information and Observation Network. 2022. "Economic losses from climate-related extremes in Europe." European Environment Agency. Accessed on November 6 2022.

and adapt in order to avoid further detriment and impairment caused by climate change, both on an economic scale and for humanity as a whole.

When asked to assess the impact of climate change and related weather pattern changes on their businesses, European firms expressed profuse concerns over the imminent physical risks and economic setbacks stemming from such issues.[11] There are, however, discrepancies in perceived business costs from the physical risks of climate change across different European regions. This can be reflected in the variation in how vulnerable specific business sectors and operations are to these climate change effects. Adding on, differences in country environments and landscapes give rise to cross-national differences in both acute and chronic climate hazards.[12] This influences regions' ability to circumvent and mitigate extreme weather fluctuations, causing certain regions to face more profound consequences from climate inaction than others.

1.1. Background

Temperature today is about 1.1°C warmer than in the late 1800s,[13] 1.01°C warmer from 1880 to 2021 according to NASA.[14] Research shows that in order to avoid the most severe impacts of climate change, global temperature needs to stay within the limits set out in the Paris Agreement: Below 2°C compared to pre-industrial levels with the aim of staying below 1.5°. To reach the goal, emissions need to be reduced by 45% by 2030 and net zero emission needs to be reached by 2050.[15] Chief of UNEP's Energy and Climate Branch, Mark Radka, ascertained that, "At 1.5°C of warming, 2.3 Billion people could be both exposed and vulnerable to heatwave events, with negative impacts on health and productivity",[16] and that, "Without action, in 2030, an estimated 80 million full-time jobs could be lost worldwide due to heat stress, resulting in economic losses of USD 2.3 trillion".[17]

Moving forward, there is a general concern that drastic climate change will continue and potentially be magnified due to tipping points, causing exponential triggers and impairments. Tipping points are defined by the Intergovernmental Panel on Climate Change (IPCC) as "critical thresholds in a system that, when exceeded, can lead to a significant change in the state of the system, often with an understanding that the change is irreversible."[18] The melting of ice sheets is especially correlated with air temperature, with the Greenland ice sheet estimated to reach its irreversible tipping point at an increased warming of 1.5°C.[19] This implies that even if we manage to stay within the Paris Agreement's guideline of reducing global temperature

[11] Fotios Kalantzis, et al. 2021. "European firms and climate change 2020/2021: Evidence from the EIB Investment Survey." European Investment Bank.
[12] Climate-ADAPT. n.d. 'Country profiles'. The European Commission and the European Environment Agency. Accessed on October 29 2022.
[13] The United Nations - "For a livable climate: Net-zero commitments must be backed by credible action."
[14] NASA/GISS. 2021. 'Global Temperature.' National Aeronautics and Space Administration. Accessed on November 27 2022.
[15] The United Nations - "For a livable climate: Net-zero commitments must be backed by credible action."
[16] UN Environment Programme - "As heatwaves blanket Europe, cities turn to nature for solutions."
[17] UN Environment Programme - "As heatwaves blanket Europe, cities turn to nature for solutions."
[18] Martina Igini. 2022. "The Tipping Points of Climate Change: How Will Our World Change?" EO. Accessed on November 12 2022.
[19] Igini - "The Tipping Points of Climate Change: How Will Our World Change?"

escalation by at least 2°C, we still risk facing extensive economic and humanitarian consequences predominantly from, but not exclusively, increased temperatures and the compounding effects thereafter.

For the purpose of this work, it is important to establish the difference between climate and weather. Climate is referring to long-term distributions of outcomes, such as averages over decades, generations, or centuries, whilst weather is referring to short-term, often local, realizations from said distribution. These commonly vary a lot, often cyclically, over numerous periods of time. The impact of such realizations will provide insights about the emphasis of the distribution as a whole. Hence, if short-run fluctuations in weather would be shown to have no significant impression on production, then long-run changes in climate, towards which adaptation over time is possible, would plausibly have non-significant impressions as well.[20]

1.1.1. Long-term Climate

The year 2021 was depicted as a 'make or break' year by the UN Framework Convention on Climate Change's (UNFCCC) Secretary-General António Guterres. The UNFCCC's Initial NDC Synthesis Report from February 2021, which measures the progress of national climate action plans, was referred to as a 'red alert for the planet', stating that "Nations are 'nowhere close' to the level of action needed to fight global warming".[21] Further understanding of the economic repercussions for firms might be one way to raise the stakes for corporations and be an effective spark for much-needed revision.

The IPCC predicts that, going forward, extreme climate events will become evermore frequent around the world.[22] Additionally, feedback from the concerns of European firms,[23] show that they also, at least to some extent, share this view. In the beginning of 2021, the EU's adaptation strategy was adopted by the European Commission and is planned to lead the EU to a full adaptation "to the unavoidable impacts of climate change" by the year 2050.[24] Actions include, but are not limited to, improving climate knowledge and managing the uncertainty surrounding climate change by accumulating more extensive and accurate climate loss data, and improving systematic adaptation in terms of policy making through more local adaptation actions.[25] It is intended to ensure that Europe is readily prepared to manage both risks associated with climate change and adaptation to its impacts. By building resilience, damages and economic losses within the EU can drastically be minimized.

Europe as a whole is less harmed by natural risks than many other continents, however, there is a wide internal variation across different areas and countries. For instance, Southern regions are

---

[20] Melissa Dell, et al. 2014. "What Do We Learn from the Weather? The New Climate–Economy Literature." *Journal of Economic Literature*52 (3): 740–798.
[21] UN News. 2021. "UN climate report a 'red alert' for the planet: Guterres." The United Nations. Accessed on November 4 2022.
[22] European Environment Information and Observation Network - "Economic losses from climate-related extremes in Europe."
[23] Kalantzis, et al. - "European firms and climate change 2020/2021: Evidence from the EIB Investment Survey."
[24] Climate-ADAPT. n.d. "EU Adaptation Strategy A new EU adaptation strategy." The European Commission and the European Environment Agency. Accessed on October 30 2022.
[25] Climate-ADAPT - "EU Adaptation Strategy A new EU adaptation strategy."

comparatively more susceptible to the direct effects of natural hazards than the rest of Europe. Furthermore, their reliance on sectors such as travel and tourism, which are likely to be highly sensitive to extreme weather, additionally makes them relatively vulnerable to indirect effects of climate change.[26]

In April 2022, the IPCC released their climate report stating that, "it's now or never" to limit warming to 1.5°C compared to pre-industrial levels. There are currently extensive pledges and policies in place to limit carbon emissions and stay within the goals set out in the Paris Agreement. However, according to the IPCC's estimates, even if these would have been fully implemented before the start of 2021, global temperature increase would still reach 3.2°C before the year 2100.[27] Climate change is further expected to not only be limited to increased temperatures, but also altered precipitation patterns, rising sea levels, and affect the frequency, location, and intensity of storms.[28] Some regions are facing more extensive deviations from the mean of climatic change than others, creating a necessity to analyze the behind the scenes economic repercussions of weather deviations.[29]

1.1.2. Short-term Weather

Although accurate proxies for climate change are difficult to obtain, weather observations are frequently used in literature to parallel climate change and its effects. Climate related changes in weather patterns are currently worrying European firms,[30] and estimating the economic depletion that surfaces from these weather upsurges is essential for motivating and incentivizing firms to further allocate resources towards mitigation actions. Actions such as air conditioning, migration, and production factor reallocation could weaken the losses incurred by individual firms. Examining their abilities to adapt and adjust to changes in weather could be beneficial in determining the extent of productional impact from short-term weather variations, as well as give an indication of the effects of any potential long-term climatic trends.

To conclude, an increase in temperature seems to be inevitable, however, the magnitude of such a change is not fixed and heavily grounded in current action. Mitigation of the risks and adaptation to damages caused by climate change is vital to optimize firm performance in turbulent weather scenarios. The lack of estimates and assessments of damages on local levels are not easing the current state: local entities are missing crucial cost data that are necessary to make executive decisions.

[26] Alvise Lennkh, et al. 2021. "Extreme climate events in Europe: rising economic losses can lead to greater sovereign ratings divergence." Scope Ratings.
[27] Olivia Lai. 2022. "IPCC Climate Report Warns 'It's Now or Never' to Limit Global Warming As 1.5C Becomes More Out of Reach." EO. Accessed on October 26 2022.
[28] P Forster, et al., 2007: Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., and Miller, H.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
[29] Dell, et al. - "What Do We Learn from the Weather? The New Climate–Economy Literature."
[30] Kalantzis, et al. - "European firms and climate change 2020/2021: Evidence from the EIB Investment Survey."

1.2. Literature Review

There is currently an array of research and literature on the topic, with varying methods, approaches, and regional focuses. Weather variables, such as temperature and precipitation, show signs of having economically and statistically significant effects on several economic outcomes. Models utilizing the variation in weather have provided important insights regarding the economic losses associated with climate change.

1.2.1. Temperature

There is extensive literature regarding the adverse link between increased temperature and production losses. Meta-analyses on the aggregate relationship between temperature and output have been relatively consistent, centering around an approximate 2% loss per 1°C increase in temperature. Studies are similarly consistent in their assessment of the impact of labor productivity, estimating a labor productivity loss of approximately 2% per 1°C increase in temperature, for baseline temperatures above 25°C.[31]

Studies that have used a so-called bin approach,[32] have shown similar results. In India, one additional day between 35-50°C, rather than 0-20°C, was associated with a 0.22% reduction in annual output. Furthermore, having an additional day between 23-27ºC reduced India's annual output by an average of 6-8%.[33] The impacts of daily temperature changes on production have also been examined in China; where it was found that an additional day with temperature above 90ºF, rather than between 50-60ºF, reduces production output by 0.45% and Total Factor Productivity (TFP) by 0.56%.[34] The aggregate average output loss for Chinese firms was estimated to reach $0.43 Trillion in 1998 values and each additional day with temperature above 90ºF was associated with an output loss of $1.89 Billion, relative to the impact of temperature between 50-60ºF. These effects were almost exclusively driven by the negative relationship between temperature and TFP.[35]

In the medium-run, expected climate change in terms of increased temperatures was estimated to cause production output losses of 5.71%, translating to 1.83% of China's total GDP. A 1ºC increase in annual mean temperature was expected to reduce China's GDP by 1.66%, thereby inducing large economic losses following climate change and subsequent higher temperatures.[36] Other developing countries have shown signs of facing similar losses, where a 1ºC increase in

[31] Dell, et al. - "What Do We Learn from the Weather? The New Climate–Economy Literature."
[32] The bin approach is further explained in section 2.1.
[33] E. Somanathan, et al. 2021. "The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing." *Journal of Political Economy* 129 (6): 1667-1945.
[34] TPF refers to a weighted average of both capital and labor productivity.
[35] Peng Zhang, et al. 2016. "Temperature Effects on Productivity and Factor Reallocation: Evidence from a Half Million Chinese Manufacturing Plants". *Journal of Environmental Economics and Management* 88: 1-17.
[36] Zhang, et al. - "Temperature Effects on Productivity and Factor Reallocation: Evidence from a Half Million Chinese Manufacturing Plants."

annual average temperature is associated with economic losses corresponding to 1-2.5% of national GDP.[37]

It is estimated that approximately half of the negative short-run effects of increased temperature could potentially be offset by adaptation.[38] Temperature's negative effect on production output in India showed to be diminishing over time, suggesting that some adaptation (such as targeted investments in adaptation tools) to changing weather is taking place. However, this workplace adaptation was shown to be insufficient to eliminate all negative effects of heat on production.[39] Another mechanism through which such adaptation could take place is through factor reallocation. However, the idea that large-scale climate damages, such as those observed in China, would be for the most part mitigated or undone solely by adaptations made to weather changes is so far not fully supported in the literature.[40]

An additional study found negative effects of higher temperatures on economic growth in poor countries that were larger in the long-run than the short-run specification, suggesting that intensification of weather effects could be outweighing any possible adaptation mechanism over time. Contrarily, the long-run effects showed a non-significant relationship between temperature and economic growth in rich countries.[41] Hence, extensive adaptation could potentially be more supported in rich countries than in poor countries. However, caution should be taken to the fact that modeled estimates are likely telling us more about modest temperature changes closer in time rather than extreme long-term changes.[42]

1.2.2. Precipitation

There is a scarce amount of studies pointing towards significant effects of precipitation on economic activities. Precipitation's influence on agricultural income has been tested in Brazil, estimating that income gets reduced by 4% from a one standard deviation increase in rainfall.[43] Weather examined in 60 African and non-African countries during 1960-1990 showed that higher rainfall yielded faster growth in Sub-Saharan Africa, whilst not holding true for drier and richer countries.[44] Similarly, unusually low precipitation in African countries exhibits a negative influence on income per capita, however, with no robust effects for non-African countries.[45]

---

[37] Solomon M. Hsiang. 2010. "Temperatures and Cyclones Strongly Associated with Economic Production in the Caribbean and Central America." *Proceedings of theNational Academy of Sciences*107(35): 15367–72, and Melissa Dell, et al. 2012. "Temperature Shocks and Economic Growth: Evidence from the Last Half Century." *American Economic Journal: Macroeconomics* 4 (3): 66–95.
[38] Francesco Caselli, et al. 1996. "Reopening the Convergence Debate: A New Look at Cross-Country Growth Empirics." *Journal of Economic Growth*1 (3): 363–89.
[39] Somanathan, et al. - "The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing."
[40] Dell, et al. - "What Do We Learn from the Weather? The New Climate–Economy Literature."
[41] Dell, et al. - "Temperature Shocks and Economic Growth: Evidence from the Last Half Century."
[42] Dell, et al. - "What Do We Learn from the Weather? The New Climate–Economy Literature."
[43] F. Daniel Hidalgo, et al. 2010. "Economic Determinants of Land Invasions." *Review of Economics and Statistics*92 (3): 505–23.
[44] Salvador Barrios, et al. 2010. "Trends in Rainfall and Economic Growth in Africa: A Neglected Cause of the African Growth Tragedy." *Review of Economics and Statistics*92 (2): 350–66.
[45] Dell, et al. - "What Do We Learn from the Weather? The New Climate–Economy Literature."

There is currently a lack of substantial, unambiguous evidence that precipitation is significantly affecting production output. Most studies that examine the effect of both temperature and precipitation have found limited direct effects on economic activities from rainfall.[46] The influence of precipitation on output seems to either be minute, or insignificant, where only extremely heavy precipitation has been found to cause modest negative effects. Despite the amount of studies finding important relationships between weather in general and economic variables, some conflicting results, particularly regarding precipitation, remain.[47] Studies on average precipitation have shown that effects are not robust enough across different sector level specifications to draw any concrete conclusions.[48] Hence, if there is a significant causal relationship, it is not yet entirely clear what it looks like.

In conclusion, the implications of precipitation on economic activity are ambiguous, whilst for temperature, they are quite consistent and straightforward. The current field of research has shown the existence of a strong, negative relationship between temperature and certain economic activities, both within and across countries, and with a magnified effect for poor countries. These effects, however, cannot confidently be said to hold for other weather variables, such as precipitation. Temperature is established to be a strong predictor of economic income, whereas precipitation is not clear to be.[49]

1.3. Our Contributions

To the best of our knowledge, there are still contributions to be made in this field of research. Even though current literature has thoroughly examined temperature fluctuation damages in different regional and economical settings, these have mainly been centered around relatively warmer and poorer countries, such as India and China. Research on cooler countries, which generally have a weaker relationship between regional temperature and economic income,[50] is an under-investigated sector of the field. To fill in some of the research gap in terms of geographical limitations, we are expanding previous litterature's regional application to a European setting. This will constitute one of our main contributions.

Additionally, few studies consider data beyond 2000. Therefore, we will further add to previous findings by considering more modern time spans, covering the years 2000-2020. Finding more up-to-date estimates on economic impact further ensures relevancy for current policy decision making; which is crucial in an ever changing world of climate and weather. The aforementioned results back the relevance for our study and provide essential methodology attributes, however, specific models on firm production have previously only been done for single entities, such as

---

[46] Melissa Dell, et al. 2009. "Temperature and Income: Reconciling New Cross-Sectional and Panel Estimates." *American Economic Review* 99 (2): 198–204, found little to no impact of average precipitation on per capita GDP, neither within nor across countries, for municipal-level data in American countries. Dell, et al., in "Temperature Shocks and Economic Growth: Evidence from the Last Half Century", control for mean precipitation in their temperature regression, finding no significant effects of average precipitation levels.

[47] Dell, et al. - "What Do We Learn from the Weather? The New Climate–Economy Literature."

[48] Benjamin F. Jones, et al. 2010. "Climate Shocks and Exports." *American Economic Review* 100 (2): 454–59.

[49] Paul J. Burke, et al. 2010. "Do Output Contractions Trigger Democratic Change?" *American Economic Journal: Macroeconomics* 2 (4): 124–57.

[50] Dell, et al. - "What Do We Learn from the Weather? The New Climate–Economy Literature."

India and China. The magnitude of productional impact differs, both across continents and across more local geographical regions, making extending beyond a single country a necessary analysis and opens the door for more intriguing insights.

1.4. Research Questions

(1) What are the productional losses and/or gains associated with weather fluctuations for European firms?

(2) Are there any differences in production losses and/or gains related to weather fluctuations depending on regional location within Europe?

(3) What are the implications of the effects of weather fluctuations on European firms?

1.5. Thesis Outline

The thesis is outlined as follows. Section 2 will be dedicated to the methodology, including the theoretical framework, collection and description of data, assumptions made, and the model setup. Section 3 consists of findings, including results from the baseline and heterogeneity regressions, and conclusions. Finally, Section 4 consists of a summary of the thesis as a whole, including a short walkthrough of the introduction chapter, the methodology, the main findings, and the conclusions. References and appendices are found in Section 5, 6, and 7.

2. Methodology

The methodology consists of two main datasets and two main methodological specifications. The first dataset utilized is the daily weather observations throughout Europe, capturing the exogenous variation in local daily weather fluctuations across European regions. The second consists of regional economic data observations needed to assess the relationship between weather and firm production. The foundational models used to estimate this relationship are baseline regressions between European weather and production as a whole. These are then built upon by including subregional dummy variables to unveil any heterogeneous treatment effects across the sample. Finally, a lagged effect model for temperature is estimated as an indicator of adaptation or intensification over time. These models rely on two main methodological specifications: the Cobb-Douglas production function and the bin approach.

2.1. Theoretical Framework

Multi-linear regressions will be employed to estimate the relationship between exogenous variation in daily weather and European firm production. The relationship between weather and production output will be of central focus, but the channels through which change takes place will additionally be analyzed by testing the direct relationship between weather data and each component in firms' production function.[51]

The Cobb-Douglas production function will be used as an estimate for firms' production function. The standard Cobb-Douglas production function for one region at one point in time looks as follow:

$$Y = TFP * L^{a} * K^{b}$$

Where Y is the firms' output, TFP is the Total Factor Productivity, the weighted average of labor and capital productivity. L stands for labor, K for capital, and a and b for output elasticity of substitution for labor and capital, respectively. Linearizing and taking the natural logs of the standard equation for each region and each year of interest yields the following:

$$y_{rt} = \beta_{l} l_{rt} + \beta_{k} k_{rt} + u_{rt}$$

Where the subscript r indicates each region and the subscript t indicates each year of interest. This linearized and logged Cobb-Douglas production function will serve as the model for the firms' production specification and constitute our general model setup. Worthy to note is that the logarithm of the TFP here becomes the residual/error term, measured by the Solow residual,[52] such that the natural log of TFP is estimated by:

$$u_{rt} = y_{rt} - \beta_{l} l_{rt} - \beta_{k} k_{rt}$$

This implies that everything regarding output that is not explained by capital or labor, or the elasticity of substitution between the two, will end up in, and be considered explained by, the productivity parameter. This is the default assumption of the Cobb-Douglas production function.

To fully realize the economical impact of climate change and its subsequent effects on weather, nonlinear effects are pivotal to understand. A rightward shift in the distribution of mean temperature, which is the expected pattern due to climate change going forward, would create a disproportionate increase in the number of hot days. The larger the disproportionality of these nonlinear changes are, the greater the impact of nonlinear damages. The bin approach, which is unrestricted to linearities and considers changes in the frequency at which observations fall into different bins, value ranges, allows for a flexible estimation of the relationship at hand and reveals nonlinearities between weather and firm production.[53] The bin approach is heavily used in previous literature, mainly for its benefit of not assuming a linear relationship between weather

[51] Each component besides the exponents representing labor and capital elasticity, as the used production function, will be logarithmic.
[52] The Solow residual refers to the part of growth in output that is not attributable to the growth in inputs. Hence, the rise in output once production factor inputs, capital and labor, are constant. In other words, TFP is the part of production output growth that capital accumulation and labor increases do not account for.
[53] Dell, et al. - "What Do We Learn from the Weather? The New Climate–Economy Literature."

and production variables.[54] Rather, it allows a non-specific functional form to be best fitted to the observations for each weather variable and each region's individual production function.

To explain the intuition behind the framework, it can be thought of as if there are only two days in a year for a given region, where each day is either normal or hot (two temperature bins) and that region's production corresponds to a Cobb-Douglas production function. To simplify further, it could be assumed that there are only two years of interest, t and t+1, and that productional output on a normal day is two products while productional output on a hot day is one product. If there is one normal and one hot day in the first year, t, while both days are hot in t+1, this will leave firms' production in that region with an output loss of 33%.[55] The channel(s) through which this loss occurs could be attributable to one or both the input factors, labor and capital, and/or TFP.

In such a model, there is an inherent risk of multicollinearity as the independent variables, the bin frequency, will inevitably be inter-correlated. The estimation of the regression model will then find it difficult, or impossible, to separate the effects of the independent variables, hindering it from accurately estimating the coefficients. Potential multicollinearity when using the bin approach could be eliminated by using one of the bins as reference point, to which the other bins' estimated coefficients would be relative to. The estimation would remain independent of the choice of reference bin and would further make the results more intuitive.

2.2. Empirical Method

The methodological setup provided in the previous section will be applied to our European setting in order to assess the productional losses and/or gains associated with weather fluctuations for European firms, its implications, and any regional differences across Europe.

To estimate an as accurate relationship as possible, Europe is divided into smaller regions using the Nomenclature of Territorial Units for Statistics (NUTS). The territorial units consist of three size levels across the EU27+UK region and nine additional European countries.[56] Level 1 constitutes major socio-economic regions, level 2 constitutes basic regions for the application of regional policies, and level 3 constitutes small regions for specific diagnoses.[57] These regions undermine national borders, hence a NUTS region can only be assigned to one country. However, they are not restricted to municipalities or other similar national layers of borders. The

[54] Previous literature has for example used daily temperature bins to assess the nonlinear relationship between crop yields and temperature (Wolfram Schlenker, et al. 2009. "Nonlinear Temperature Effects Indicate Severe Damages to U.S. Crop Yields under Climate Change." *Proceedings of the National Academy of Sciences* 106 (37): 15594–98) and to assess the impact of temperature on labor productivity and absenteeism (Somanathan, et al. - "The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing"). The approach is also used in Andrea Caggese, et al. 2022. "Climate Change and Firm Dynamics".

[55] With production of 3 products in year t and 2 products in year t+1, output loss is equivalent to ⅓ of production, 33%. A similar reasoning regarding the interpretation of bin estimates is found in Zhang, et al.'s "Temperature Effects on Productivity and Factor Reallocation: Evidence from a Half Million Chinese Manufacturing Plants."

[56] These additional countries are Iceland, Lichtenstein, Norway, Switzerland, Montenegro, North Macedonia, Albania, Serbia, and Turkey.

[57] Eurostat. n.d. 'NUTS - Nomenclature of territorial units for statistics - Background'. The European Union. Accessed on October 14 2022.

NUTS definition was first defined in July of 2003. The borders and names are regularly updated, but the regional classifications are intended to be stable for at least three years, ensuring that regional data is referring to the same regional units over a predefined period of time. Adaptation of the sixth amendment took place on August 8th, 2019 and as of January 1st, 2021 and up until the time of writing, these are the definitions used for transmission of data to the European Commission.[58] 2021's NUTS classification includes 92 level 1 regions, 372 level 2 regions, and 1166 level 3 regions across 37 European countries.[59]

Level 2 is mainly used for the application of policy making for regional development, to enable cohesional policies throughout Europe,[60] and to determine geographical eligibility from structural and investment funds.[61] It is the most relevant level for analysis regarding policy making on the European regional level and therefore, level 2 will be used for the methodological application in this thesis. The NUTS 2 regions usually have a population of around 800,000 to 3 Million people.[62] As a result, the number of level 2 regions in each country differ substantially. In some smaller countries, such as Estonia, Cyprus, and Luxembourg, there is only one level 2 region,[63] while for larger countries such as the UK and Germany there are 41 and 38 level 2 regions respectively.[64] A depiction of the regional borders is found in Figure A, Appendix A.

For the different components in the production function, output is defined as Gross Value Added (GVA) for each region (in Euros): the gross difference between output and intermediate input. Labor is defined as numbers of hours worked and capital as Gross Fixed Capital Formation (GFCF) (in Euros). GFCF is a component of the Gross Domestic Product (GDP) for each region and captures the net capital expenditure (acquisitions less disposals of assets) when GDP is measured through the expenditure approach.[65] Labor elasticity of substitution is defined as Employee Income over GVA, where employee income should be interpreted as a proxy for each region's wage bill. Capital elasticity of substitution is defined as (1-labor elasticity).[66] For regional weather variables, daily observations of max temperature (in ℃) and accumulated precipitation (in mm) will be used.[67] To ease the interpretation of the forthcoming results, the weather observations' values are scaled down by 100.

---

[58] Eurostat. n.d. 'NUTS - Nomenclature of territorial units for statistics - History of NUTS'. The European Union. Accessed on October 14 2022.
[59] Eurostat - 'NUTS - Nomenclature of territorial units for statistics - Background'.
[60] Eurostat - 'NUTS - Nomenclature of territorial units for statistics - Background'.
[61] Eurostat. n.d. 'Regions - Background'. The European Union. Accessed on October 14 2022.
[62] Destatis Statistisches Bundesamt. n.d. "NUTS classification The hierarchical categorisation of EU territories and regions." The Federal Statistical Office and Eurostat. Accessed on October 16 2022.
[63] In those cases, the level 2 region is the same as the level 1 region and holds the national borders of the country as region definition.
[64] Eurostat. 2020. "Correspondence between the NUTS levels and the national administrative units." The European Union. Accessed on November 20 2022.
[65] This version of capital within the Cobb-Douglas production function is used in, among others, J. Harrasova, et al. 2020. "Estimating the elasticity of substitution between capital and labour." *Fraser of Allander EconomicCommentary* 44 (4).
[66] The implications of assuming constant returns to scale will be elaborated upon in section 2.2.
[67] Max daily temperature, rather than daily average temperature, will be used, being a more accurate proxy for daily temperature. Max temperature generally occurs during working hours and is therefore more useful when examining heat exposure related to production, especially in regards to labor effects. See similar reasoning in Somanathan, et al. - "The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing."

To use daily weather observations and be able to test its impact on the above-mentioned yearly economic instruments, each weather variable's daily observed value is assigned to a bin, such that all observations are assigned to range brackets corresponding to the bin it falls into. To aggregate the daily observations to annual levels, the number of days falling into each bin in each year for each region is counted. A vector of the frequency of these counted days constitutes the weather distribution for each year within each region. The bins are non-overlapping and range across all observations. Hence, all weather observations are assigned to a bin and no observation is assigned to more than one bin.[68] Therefore, each region's weather distribution adds up to 365 counted days, 366 in the case of a leap year. The distribution of weather observations, represented by the amount of days in each separate bin, will then be run on the economic parameters in the above-mentioned model.[69]

Potential nonlinearities, as previous literature suggests to be present between weather and production,[70] will be displayed through the nonparametric bin approach, which also enables extraction of the year-to-year variation in regional weather and tests the daily input on annual output. Max temperature and accumulated precipitation observations for each year between 2000-2020 and for each NUTS 2 region are assigned to a bin corresponding to its value.[71] For max temperature, the bins are, in ℃: {[<-5], (-5-0], (0-5], (5-10], (10-15], (15-20], (20-25], (25-30], (>30]}. For accumulated precipitation, the bins are, in mm: {[0], (0-10], (10-20], (>20]}.[72] The upper and lower bins have open bounds to avoid noisy coefficient estimates around the most extreme weather observations, where there are only a few observations.

The precipitation bins were unequally divided in order to capture the impact of the number of days without precipitation, completely dry days, compared to days with any level of precipitation. To avoid multicollinearity, the coefficients for bin (15-20] for max temperature and bin (0-10] for accumulated precipitation will be normalized to zero, turning all other bin coefficients into the impact on the dependent variables relative to their respective reference bin. For temperature, this bin was chosen based on it being the most frequent observation, creating a somewhat symmetrical point of reference. As for precipitation, the bin was chosen to capture the effects of dry days versus some level of precipitation, making the closest bin after 0 mm the best alternative to compare the juxtaposition.

Each NUTS 2 region is then matched with its corresponding set of economic parameters in the production function. Once done, the dataset consists of regional yearly weather (in bin frequencies) and regional yearly production data, for the years 2000-2020. Each weather variable

---

[68] A similar methodological reasoning is provided by Somanathan, et al. in "The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing."
[69] Similar model setups, using the bin approach together with the Cobb-Douglas production function, are found in, among others, Zhang, et al.'s "Temperature Effects on Productivity and Factor Reallocation: Evidence from a Half Million Chinese Manufacturing Plants" and Somanathan, et al.'s "The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing."
[70] Dell, et al. - "What Do We Learn from the Weather? The New Climate–Economy Literature."
[71] An example of the frequency distribution of temperature in a region for one year is found inFigure B, Appendix A.
[72] Histograms of the distribution of temperature and precipitation observations across our full sample are found in section 2.3.3.

is then regressed on each of the four Cobb-Douglas components, output, labor, capital, and TFP,[73] to get an overview of the relationships at play. This constitutes the two baseline models, one for max temperature and one for accumulated precipitation, and will be the focal point of the main conclusions drawn later. Examining precipitation, rather than exclusively temperature, provides valuable insights regarding the role precipitation plays in the relationship between weather and firm production; something that current research has only found ambiguous and inconsistent evidence for.

Once these relationships are established, the presence of heterogeneous treatment effects across subregions will be investigated: whether the results are in fact mainly driven by certain subregions in the sample rather than evenly by the sample as a whole. European subregions are defined in accordance with the United Nations Geoscheme classification,[74] and each NUTS 2 region is exclusively assigned to one subregion: Southern, Northern, Eastern, Western, or Central Europe, such that no region is left unassigned and no region is assigned more than once. The subregional borders in the final sample of NUTS 2 regions looks as follows:

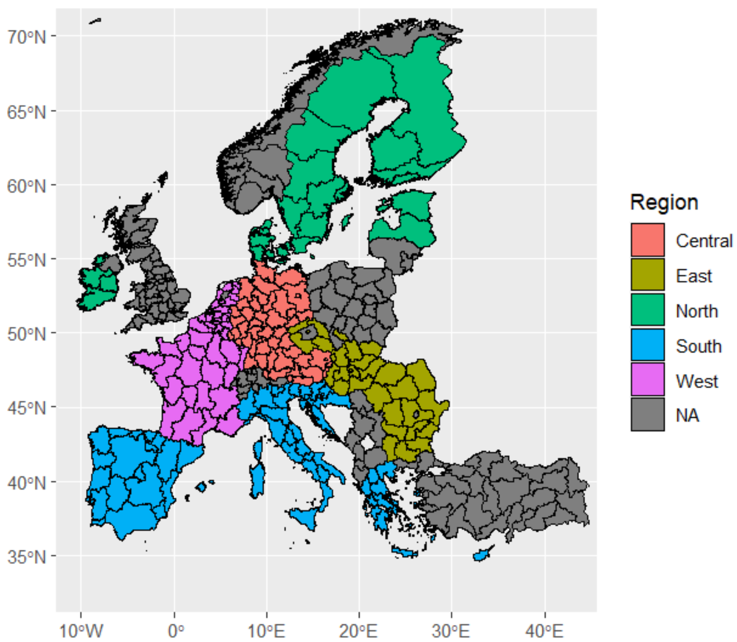

Figure 1: The borders for the five European subregions: Southern, Northern, Eastern, Western, and Central Europe, for all NUTS 2 regions included in the final sample. Data source: Eurostat and The United Nations Geoscheme Classification.[75]

Whether the impact of temperature fluctuations is in fact fully impacting firm production immediately, rather than later on, will be examined as well. If economic damages caused by temperature disruption are delayed, such that total losses related to changed temperature patterns in a year do not exclusively take place in that year, the true, complete effects of the baseline models will be underestimated. Therefore, adding lagged temperature bins to the model will

[73] Where each region's TFP is calculated as the Solow residual seen in section 2.1.
[74] Jason Shvili. 2021. "Regions Of Europe." WorldAtlas. Accessed on November 5 2022.
[75] NA values correspond to NUTS 2 regions that are dropped during the data cleaning process, which is explained in section 2.3.2.

enable us to assess any additional effects taking place in the coming year. Firm production could either see increasing effects over time, where implications from weather fluctuations are delayed and intensify, or be able to adjust to the effects across years and by that experience diminishing effects over time. These results could be of further interest in regard to future climate change and its corresponding impact on weather patterns.

Potential future damages or gains from European production alterations caused by climate change will also be examined by looking at the potential impact of the IPCC's estimated 3.2°C temperature rise before 2100.[76] When doing so, frequency and geographical distribution of high temperatures, above 30℃, in 2020 across regions will be the reference year. The expected rise in temperature is relying on two external estimates: that temperature today is about 1.1°C warmer than in the late 1800s,[77] and that temperature, according to the IPCC, is expected to rise to at least 3.2°C before the year 2100. This implies that global temperature at the end of this decade could be expected to rise by 2.1°C from 2020 to 2100.[78]

This prediction should be seen as a pure indication rather than a valid estimate. The ability to reliably predict outcomes over a timespan of this size is limited and to what extent such an indication holds true will depend on several aspects unaccounted for. Some of these aspects are adaptation of mitigation strategies imposed by governments and corporations, intensification of climate change over time, and general equilibrium effects.[79] Lastly, the distribution of high temperature frequency across Europe will be discussed. The discussion will be centered around the ongoing trend of a hotter climate and how its correspondingly higher temperatures could be expected to affect European firms' production in the coming decades. The implications of this and potential adaptation strategies for these firms will also be discussed.

Weather does provide an indication and some guidance of where climate change is heading, to the extent it is related to long-term weather. However, it is important to emphasize that the effects of changes in short-term weather patterns are not necessarily directly translatable to the effects of long-term climate change.[80] The extent to which our findings provide valuable and accurate insights regarding long-term climate change is partly dependent on the strength of long-run adaptation and intensification forces. An overpowering adaptation over time would make our estimates an overestimation of climatic effects, such that the impact of weather shocks would be larger than the impact of climate change. Whilst a substantial intensification of climate effects would make our estimates an underestimation in the long-run, such that the impact of weather shocks would be smaller than the impact of climate change.[81] Hence, whether adaptation or intensification is the more dominant driver will be a key determinant of the implications for our results in regards to future climate change.

[76] Lai - "IPCC Climate Report Warns 'It's Now or Never' to Limit Global Warming As 1.5C Becomes More Out of Reach."
[77] The United Nations - "For a livable climate: Net-zero commitments must be backed by credible action." The UN's rather than NASA's estimate (1.01°C warmer from 1880 to 2021) and the late 1800's rather than earlier, pre-industrial, estimate will be used in order to adopt a conservative rather than a progressive measure.
[78] Since 3.2°C - 1.1°C = 2.1°C.
[79] Dell, et al. - "What Do We Learn from the Weather? The New Climate–Economy Literature."
[80] Dell, et al. - "What Do We Learn from the Weather? The New Climate–Economy Literature."
[81] Dell, et al. - "What Do We Learn from the Weather? The New Climate–Economy Literature."

2.3. Data

This section extends the described method and will cover the collection and cleaning of data, enabling us to assemble the final dataset later used. The section finishes off with describing the observations constituting the final sample and the variables at hand.

2.3.1. Method of Data Collection

Two main databases are used for data collection. Copernicus for the weather data and Eurostat for the economic data and geolocational shape maps. Weather data was derived from a gridded 0.1∘ by 0.1∘ daily weather observations dataset on max temperature and accumulated precipitation, identified by latitude and longitude positioning, requested from and obtained through the Copernicus website. To obtain the coordinates for each NUTS 2 region and assign each weather observation to its corresponding region, data was run through a point shape file for all NUTS 2 regions, obtained from Eurostat. Using the regional classifications from Eurostat specifically ensures that the datasets used for weather observations and economic parameters are regionally consistent and cohesive. Through a freely available external software, QGIS, the latitudinal and longitudinal coordinates for each region were extracted, and later exported. The gridded daily weather coordinates were compared to those obtained through QGIS to find the closest recorded weather locations. This was used as the proxy for the weather data for each region.

Regional economic datasets were obtained as publicly available information from Eurostat. GVA, number of hours worked (labor), GFCF, and employee income (for calculation of labor elasticity) for NUTS 2 regions were all directly downloaded from Eurostat's website, as extractions of Eurostat's original regional datasets. As elaborated upon in section 2.2, the regional statistics obtained through Eurostat refer to the NUTS 2021 definition, consistent across all years in the sample. New amendments regarding the region classifications have been enacted during the time period of interest, however, the affected countries have to replace historical data by time series accordingly within two years.[82] Therefore, the datasets, which are extracted during the second half of 2022, remain consistent across region classifications across the years of interest, 2000-2020.

The measurement of capital, GFCF, is by Eurostat reported in nominal terms whilst output, GVA, is reported in real terms. Therefore, to enable comparability across measures and strengthen the validity of our results, GFCF was deflated for each year of interest, 2000-2020, by the 2010 consumer price indices for each country.[83] The transformation of GFCF into real terms was done using a dataset of annual consumer price indices for each country, obtained through The World Bank.[84]

[82] Eurostat - 'NUTS - Nomenclature of territorial units for statistics - History of NUTS'.
[83] National, rather than regional, consumer price indices were applied as the NUTS regions are not limited to trade or consumption market areas. Hence, consumer price indices on a national level is a more precise measure of the consumer price indices also occurring in each region.
[84] The World Bank. "Consumer price index (2010 = 100) - European Union." 2022. The World Bank Group. Accessed on November 28 2022.

2.3.2. Data Description

Most of the NUTS 2 regions provide full sets of both daily weather data and aggregate annual economic data. However, certain regions were excluded from the analysis during the cleaning process due to a considerable amount of missing data, which could provide unwanted noise in the estimates. All regions that lacked more than five years of daily weather data or more than four years of any annual economic parameter needed for the Cobb-Douglas production function were excluded from the sample. The specifics of these requirements were customized to the sample at hand and were chosen to exclude as few regions as possible while still ensuring an adequate amount of non-missing observations.

For the most part, only a miniscule amount of regions within each country and subregion was dropped, but in some cases, especially for those countries having only one NUTS 2 region, entire countries were dropped.[85] In total, 117 regions were dropped from the original sample, out of which 110 were due to too many missing annual economic values and 7 due to missing weather observations for the years of interest.[86] Furthermore, observations corresponding to so-called “Extra-regio level 2” regions were excluded as well. These are national residuals of the NUTS 2 regions and refer to observations that cannot be precisely located to a specific position or region. The remaining regions were allowed to have occasional missing years of economic observations.

Any underlying systemics that cause Eurostat to be unable to disclose annual economic values for specific regions or countries could potentially have implications for our results. However, such regions are relatively evenly distributed across the continent. Although this could skew the estimated relationship for certain areas, the extensive amount of gathered observations makes such missing values unlikely to have fundamental implications for the overall assessed relationship for Europe as a whole or for the larger subregions.[87]

After the data cleaning process, we were left with a final sample consisting of 3,343,481 individual observations for 217 NUTS 2 regions across 26 countries over 21 years.

2.3.3. Summary Statistics

The following summary statistics present an overview of the observations and variables at hand as well as the bin frequency distributions for the aggregate weather observations across the final sample.

[85] Such countries were for example Norway and Iceland. How potential issues arriving from such exclusions will be dealt with is presented in section 2.4.2.
[86] Lists of all included and excluded NUTS 2 regions in the final sample are provided in Appendix B.
[87] This issue is further discussed in section 2.4.2.

Table 1: Summary Statistics of Weather Data

Statistic	N	Mean	St. Dev.	Min	Max
Temperature (°C)	1,660,225	14.353	9.202	−37.320	43.120
Precipitation (mm)	1,657,537	1.984	4.493	0.000	192.700

Table 1: Summary statistics of the daily weather data obtained for all NUTS 2 regions included in the final sample, for the time period 2000-2020. Data source: Copernicus and Eurostat.

Table 2: Summary Aggregate Statistics of Economics Data

Statistic	N	Mean	St. Dev.	Min	Max
Output (Euros)	4,524	43,772,262,193.000	55,363,541,347.000	706,490,000.000	674,282,760,000.000
Labor (Hours)	4,345	1,359,511,350.000	1,225,447,521.000	28,251,740.000	9,893,005,070.000
Capital (Euros)	4,319	10,485,342,533.000	13,013,105,570.000	136,673,244.000	165,460,355,707.000
TFP	4,081	11.666	4.298	2.600	24.704
Labor Elasticity	4,225	0.514	0.073	0.205	0.674
Capital Elasticity	4,225	0.486	0.073	0.326	0.795

Table 2: Summary statistics of the economic production data obtained for all NUTS 2 regions included in the final sample, for the time period 2000-2020. Data source: Eurostat.

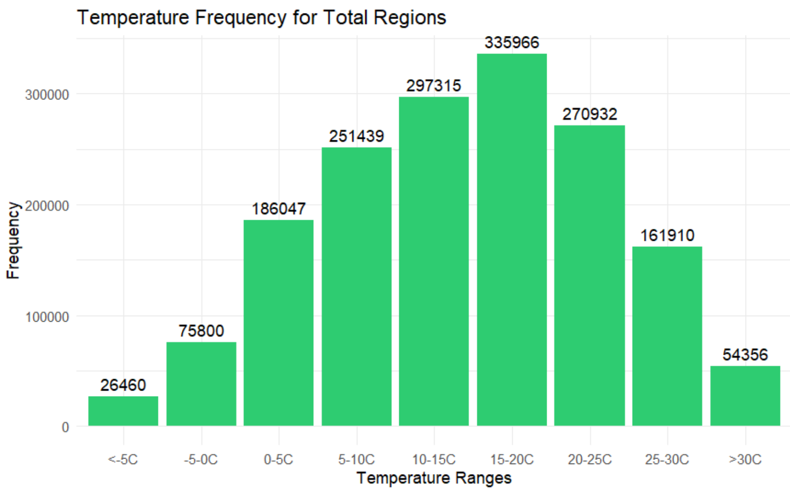

Figure 2: The distribution of daily max temperature observations within all bins across all NUTS 2 regions included in the final sample, for the time period 2000-2020. Data source: Copernicus and Eurostat.

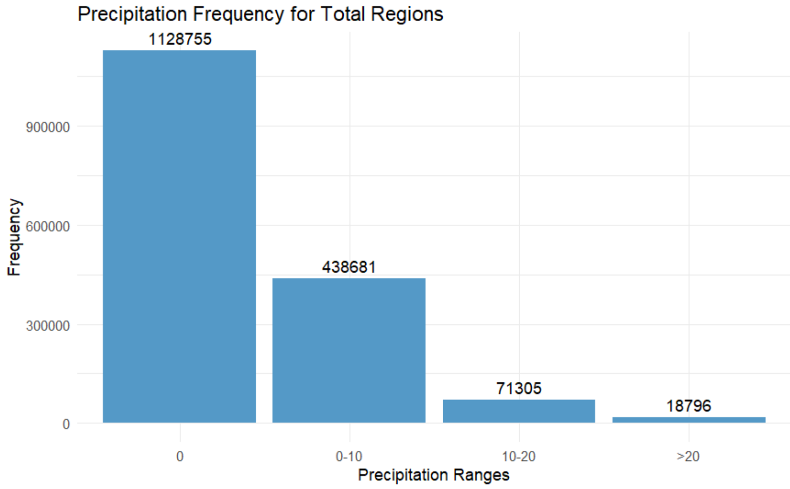

Figure 3: The distribution of daily accumulated precipitation observations within all bins across all NUTS 2 regions included in the final sample, for the time period 2000-2020. Data source: Copernicus and Eurostat.

2.4. Remarks

Before proceeding to the model specifications and findings, there are some remarks in regards to the methodology and method that need to be explicitly mentioned and elaborated upon.

2.4.1. Statistical Remarks

Since the dependent variables, output, labor, capital, and TFP are in natural logarithms, the estimated coefficients will represent the percentage change of adding one day in each bin, relative to that day being in the reference bin, (15-20] for temperature and (0-10] for precipitation. Thereby, the coefficient estimates will be the semi-elasticities of weather in regards to the production function. Each bin's estimate will indicate the marginal cost/gain, in percentage, for each firm production parameter coming from a one day increase in the frequency of that bin. As the weather variables are scaled down by 100, a coefficient of 2 will indicate a 2% increase in the dependent variable from an additional day in the corresponding bin, relative to that day instead being in the reference bin.

Regarding endogeneity in the forthcoming model specifications: to the extent that climatic variables, similar to other geographic variables, are determined exogenously, issues like reverse causation and independent variable correlations with unexpected unobservables are of minimal concern.[88] Furthermore, there are factors through which weather, especially high temperatures, are influencing firm production which are not examined, such as an increased risk of conflicts, price changes, and increased natural disaster frequency. However, such unobservables are generally not influencing factor inputs on a daily basis. Rather, these occur on time scales much longer than a single day,[89] thereby not being of interest for the interpretation of a daily variation

[88] Dell, et al. - "What Do We Learn from the Weather? The New Climate–Economy Literature."
[89] Similar reasoning for justification of excluded control variables in this kind of methodological framework is provided in Somanathan, et al. - "The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing."

scale, which is the focal point of this work. Local shocks and weather distribution's dependence on previous patterns will be adjusted for by regional and year fixed effects respectively.

2.4.2. Assumptions

There are some key assumptions made in the methodological framework that are important to explicitly mention for the sake of transparency and replication purposes. All assumptions are not necessary for the execution of the method, however, they improve the validity of the results and enclose both the width and the limitations of the conclusions later drawn.

(1) By defining the capital elasticity in the production function as (1- labor elasticity), we are assuming constant returns to scale for regional production. This implies that if all inputs in the production function double, output exactly doubles as well. For the sake of simplicity, output is here assumed to increase (decrease) proportionately to the increase (decrease) in all of the inputs, neither less nor more.

(2) The NUTS 2 regions that are excluded from the final sample, for reasons discussed in section 2.3.2., are assumed to not drive essential results that are contradicting the main findings. Magnitudes and standard errors of the estimates would likely somewhat change if this potential bias was non-existent, especially for the Eastern subregion.[90] However, it is expected to not affect coefficients' overall significance levels nor violate the main conclusions drawn from the regressions. To circumvent this, the results could be emphasized to only hold true for the specific regions observed. As many of the dropped regions are located in Eastern Europe, this subregional estimate might be less reliable than the rest. Although the estimates still provide valuable insights, caution should be taken in generalizing these results to a much broader area than the regions included in the final sample.

(3) When examining the results, it is assumed that the relationship between weather fluctuations and production variables within the assigned bins is linear. With the method used, no functional form is assumed regarding the relationship across bins. However, it is possible that there are nonlinear relationships within the bin ranges which might contradict each other, or make the overall estimate of that specific bin less precise. The presence of nonlinearities within specific bins could, for further precision, be tested using even more narrow ranges than done here, to extract a more pinpoint relationship. Although, this brings the risk of noisy estimates if there are too few observations in each bin.

(4) It is assumed that annual regional factor inputs are prespecified and independent of the distribution of weather in that particular year. Hence, firms cannot change their factor allocation during the observed year, making them unable to adjust to the realization of weather patterns continuously. However, realization of the impact of the annual weather

[90] Since many of the regions dropped during the data cleaning process, see section 2.3.2., are regions belonging to the Eastern subregion.

distribution could still cause a production update in their factor allocation across different years. With this assumption, adjustment could only take place such that regions' TFP, labor, and capital inputs adjust to previous years' regional weather distribution. Examining the lagged effects of temperature will provide some further insights regarding any such patterns of adaptation.

(5) Lastly, for the discussion of future weather effects on firm production, it is assumed that the temperature rise will be evenly distributed across temperature ranges and geographical areas. However, as current research substantiates that patterns of temperature rise will lead to an uneven rightward shift in high temperature frequency, and thereby an unproportionate increase in the frequency of hot days,[91] this assumption might be too strong to hold true. However, this will further add to our indication of future weather impact being a conservative rather than progressive measure.

2.5. Model Specifications

To estimate European production's response to weather variation, compare different subregions' varying sensitivity to weather fluctuations, and detect any potential lagging influences, the exogenous variation in weather observations is utilized. The models have their origin in the logarithmic Cobb-Douglas production function seen in section 2.1. For each climatic variable, max temperature and accumulated precipitation, and for each production parameter, output, labor, capital, and TFP, the baseline model (Eq.1) looks as follows:

$$ln\, y_{rt} = \alpha + \sum_{i=1} \beta * Bin[T]_{rt} + \beta\chi_{rt} + \delta_{r} + \theta_{t} + \varepsilon_{rt} \tag{1}$$

Where r indicates each region and t indicates each year of interest. The dependent variable, y, is the logarithm of each of the four components in the production function: output, labor, capital, and TFP. α is the regression intercept and the second independent variable, $Bin[T]$, represents the vector of all bins besides the reference bin, (15-20] for temperature and (0-10] for precipitation, for the weather variable observed.[92] The summation is the number of days in each bin in the vector multiplied by its corresponding beta coefficient, going from the first to the eighth bin for max temperature and from the first to the third bin for accumulated precipitation, again omitting the references.

Since climatic variables tend to be inter-correlated,[93] χ is included as a control variable in the form of the other weather variable, whose bins are not in vector T. For the temperature regression, this variable is the sum of precipitation (since it is accumulated) for each region each year. For the precipitation regression, this variable is the average max temperature for each

[91] Dell, et al. - "What Do We Learn from the Weather? The New Climate–Economy Literature."
[92] For max temperature T = {[<-5], (-5-0], (0-5], (5-10], (10-15], (20-25], (25-30], (>30]} and for accumulated precipitation T = {[0], (10-20], (>20]}.
[93] Zhang, et al. - "Temperature Effects on Productivity and Factor Reallocation: Evidence from a Half Million Chinese Manufacturing Plants."

region each year.[94] δ captures regional fixed effects and θ captures time fixed effects to account for regional shocks in any given year.[95] The unobservable error term, ε, is also included. Standard errors are clustered by region and year to adjust for spatial correlation within each region in a given year not accounted for by the fixed effect estimators.

Heterogeneity tests compare subregional sensitivities to weather fluctuations. To examine heterogeneous treatment effects across subregions: Southern, Eastern, Western, Northern, and Central Europe, the equation (Eq.2), for each climatic variable, max temperature and precipitation, and for each production parameter, output, labor, capital and TFP, looks as follows:

$$ln\, y_{rt} = \alpha + \sum_{i=1} \beta * Bin[T]_{rt} + \beta D_{s} + \sum_{i=1} \beta * Bin[T]_{rt} * D_{s} + \beta \chi_{rt} + \theta_{t} + \varepsilon_{rt} \quad (2)$$

Where r, t, y, α, $Bin[T]$, χ, and θ have the same interpretations as in the baseline model. The dummy variable, D, is an indicator variable for which subregion, denoted by s, each NUTS 2 region belongs to. As an example, for each region within the Northern subregion, this variable takes the value of 1 for North and the value of 0 for all other subregions: South, East, Central, and West. This works the same as in the Northern case for each respective subregion. The Central subregion serves as the baseline in this model.[96] As a result, the interaction term's, $\sum_{i=1} \beta * Bin[T] * D$, estimated coefficients constitute the additional effect on the economic outcomes for each bin in each subregion, relative to the Central subregion. To avoid the problem of collinearity between regional fixed effects and regional dummy variables appearing, this model only includes time fixed effects.[97] Standard errors are here strictly clustered on time.

For the examination of any lagged effects of temperature on economic parameters, the equation (Eq.3), for max temperature and for each production parameter, output, labor, capital, and TFP, looks as follows:

$$ln\, y_{rt} = \alpha + \sum_{i=1} \beta * Bin[T]_{rt} + \sum_{i=1} \beta * Bin[T]_{rt-1} + \beta \chi_{rt} + \delta_{r} + \theta_{t} + \varepsilon_{rt} \quad (3)$$

[94] An additional remark on the limited usage of control variables: Best practices in the field suggest inclusion of control variables only if these are credibly exogenous, for instance other variables capturing weather patterns. Other regressors could potentially also be of interest and added, but only if there is a clear, unambiguous reasoning for that variable's independence of climate (Dell, et al. - "What Do We Learn from the Weather? The New Climate–Economy Literature").

[95] As argued in section 1.1., short-term weather, such as temperature and precipitation, are randomly drawn from the local distribution of outcomes, constituting climate. However, within a specified region, fixed characteristics unique for that region might impose omitted variable bias if not adjusted for, here through regional fixed effects. Additionally, time fixed effects neutralize any common differential trends in the data and further help ensure that any relationship found is truly driven by, and identified from, idiosyncratic local shocks, within each region across time (Somanathan, et al. - "The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing").

[96] The Central regressors will automatically be omitted to avoid collinearity across dummy variables (as they include the entire sample) and does not change the estimation.

[97] Collinearity is however tested for by using alias tests for linearly dependent terms, where all subregional dummy variables generate false responses.

Where r, t, y, α, $Bin[T]$, χ, δ and θ have the same interpretations as in the baseline model. The additional bin distribution variable with subscript $t-1$ represents the previous year's bin frequency distribution for each region each year, starting from 2001.[98] The current year's bin frequency distribution, $Bin[T]$, here serves as a control variable for the lagged bin frequency distribution variable. Standard errors are again clustered on region and year.

3. Findings

All figures relevant for the upcoming analyses are found in Appendix A. The baseline regressions (Eq.1) and subregional regressions (Eq.2) will be presented first for each individual weather variable (Table 5 and 7-10 for temperature and Table 6 and 11-14 for precipitation). The lagged model (Eq.3) (Table 15 in Appendix A), used to see if there are any delayed effects of temperature on firm production, will be examined last. The potential implications of future climate change and its corresponding temperature patterns will also be discussed and looked upon visually using the expected year 2100 temperature rise.

Worthy to mention regarding the subregional regressions is that these were all estimated and run together, one for max temperature and one for accumulated precipitation, where the Central subregion served as the baseline. However, the tables are lined up and displayed such that each subregion is examined individually, relative to Central Europe. This is done solely to easen the interpretation and comparisons of the individual tables. Furthermore, all coefficient estimates are relative to the reference bins, (15-20] for temperature and (0-10] for precipitation.

Translating the effects into monetary terms and thereby assessing the magnitude of the damages/benefits of European production to changing weather patterns is done by multiplying the estimates by the average yearly output for all NUTS 2 regions in 2010. All monetary values will therefore henceforth be expressed in terms of 2010 values, corresponding to:

Table 3: Average Yearly Output Per Subregion

Subregion	Average Yearly Output
Europe	43,631,871,014
North	35,961,778,400
South	44,099,538,906
West	57,753,975,556
East	15,077,006,471
Central	54,321,623,750

Table 3: Average yearly output in 2010, in Euros, for all NUTS 2 regions included in the final sample within Europe as a whole and each European subregion.[99] Data source: Eurostat and The United Nations Geoscheme Classification.

[98] As the starting year of the sample is 2000, the first lagged bins included will be in 2001.
[99] A visual overview of the distribution of income across all NUTS 2 regions in the full sample is provided in Figure C, Appendix A.

As these are averages and not aggregated averages, the following analysis will present the mean annual change, in 2010 terms, per NUTS 2 region within their respective subregion. Although output variations will be on a NUTS 2 region level, the use of subregional names is referred to for the ease of reader legibility.

3.1. Temperature

Temperature's effect on Europe's total production is displayed in Table 5. We can deduce a negative effect on output derived from an additional day of high temperature, when compared to the reference bin. Each additional day of 25-30°C, rather than 15-20℃, is associated with an average annual output loss of 0.141% and with each additional day of temperature above 30℃, relative to the reference, the output shrinks by 0.266% on average. In economic terms, these damages equate to 62 Million and 116 Million Euros, respectively. Additionally, for each day with temperatures moving from the reference bin, 15-20℃, to a lower but still positive temperature, there seems to be a negative influence on output. These losses correspond to, on average, 0.080-0.156% of Europe's annual output.

Europe's production losses from high temperature movements are essentially exclusively driven by losses in the capital factor, with labor and TFP being statistically unaffected. Capital is exhibiting an almost inverse linear relationship with daily max temperature movements, benefitting significantly from temperatures below 0℃ whilst experiencing damages from high temperatures, relative to the reference. This inverse relationship between capital and temperature further suggests that although output manifests, however insignificantly, a negative correlation with colder temperatures, there could remain certain benefits in terms of positive capital contributions.

There is a risk that different influences within Europe are mitigating each other's effects. Adding regional indicators to the baseline regression (Table 7-10), makes it possible to examine the extent to which the different subregions contribute to Europe's estimates as a whole. This further allows for more locally concentrated impacts of changes in weather patterns to be analyzed.

The Central subregion, serving as the baseline in the upper sections of Table 7-10, shows significantly varying effects from almost all temperature movements from the reference bin. The largest effects seem to be stemming from additional days of either low, below 0°C, or high, above 25°C, temperatures. Each additional day of temperatures between -5-0°C, relative to the reference, is associated with average losses of 1.674% (909 Million Euros) and each additional day of temperatures below -5°C is associated with average losses of 1.960% (1.06 Billion Euros). These are driven mainly by capital and labor reductions. For warmer temperatures, each additional day of 25-30°C, compared to 15-20°C, is associated with extensive output losses averaging 1.549% per year. This corresponds to 841 Million Euros, mainly driven by losses in TFP. Interestingly, drastic output gains of 1.820% are extracted from each additional day above 30°C, compared to 15-20°C, driven by improved capital and labor production factors from the highest temperatures.

The lower section of Table 7 provides insights to the temperature effects at play in the Northern subregion of Europe. Relative to the Central subregion, the North is relatively unaffected. For each additional day moved from the reference bin to any of the middle bins, -5-25°C, the effects on output are insignificantly different from those seen in the Central subregion. However, in the extreme ends there are indications of extensive output losses related to the highest temperatures and significantly lower output reductions for the lowest. Each additional day moving from 15-20°C to above 30°C in the Northern region corresponds to an average production loss of 6.465%,[100] 2.32 Billion Euros, which is significantly higher than the loss seen in the Central subregion. Furthermore, each additional day moving from 15-20°C to below -5°C corresponds to an average loss of 0.901%, 324 Million Euros, significantly lower than the loss seen in Central Europe. The sensitivity to higher temperatures seems to be driven by sensitivities in both labor and capital factors whilst the limited losses from colder temperatures seems to be driven mainly by improved TFP arising from colder weather. Based on this, the North is less affected by colder temperatures than Central, however, warmer temperatures are conversely considerably more damaging.

Examining Table 8 and Southern Europe, it is evident that the Southern subregion is significantly less affected in terms of negative output losses compared to the Central subregion. For the highest temperatures, an additional day above 30°C relative to the reference bin, impacts are not statistically different from the output gain seen in Central Europe. Furthermore, the South shows extensive production benefits from additional low temperature days. Each additional day below -5°C, rather than that day being between 15-20°C, generates average output gains corresponding to 1.04% of annual output, translating to 459 Million Euros. This seems to be driven by improvements in all three production factors. Relatively high temperatures, 25-30°C, rather than 15-20°C, are also significantly improving Southern output by 6.663% on average. This seems to be channeled through labor and TFP improvements, contrasting the inverse effects seen in Central Europe.

When looking at the Western subregion relative to Central, Table 9, it is shown to be consistently less affected by changes in temperature frequencies across all temperature bins. Losses related to days moving from the reference to slightly lower temperatures, 10-15°C or 5-10°C, are corresponding to average output losses of 0.084% (49 Million Euros) and 0.115% (66 Million Euros), respectively. These output reductions are substantially lower than those seen in Central Europe. The highest temperature bin, above 30°C, generates an average output increase of 3.521% for each relative additional day, corresponding to 2.03 Billion Euros. Furthermore, colder temperatures seem to have a negative impact on the output capabilities of the Western subregion, although these losses are lower than for Central. An additional day in the -5-0°C bin, relative to 15-20°C, is associated with an average output contraction of 0.654%, corresponding to 378 Million Euros. The impact on production inputs is however somewhat ambiguous as they are insignificantly different from those seen in the Central subregion.

[100] As the additional effect, relative to the Central subregion, is the interaction terms solely. However, the total effect from the subregion observed is the additional effect from the interaction term added to the baseline effect seen in Central. Hence, in this case 1.82% - 8.285% = -6.465%.

The Eastern subregion, displayed in Table 10, shows similar responses to changing weather patterns as in Northern Europe. It is facing significantly larger average output losses from additional high temperatures while simultaneously facing significantly lower average output losses from colder temperatures, relative to the Central subregion. For East, each additional day moving from the reference bin to above 30°C is associated with an average loss of 1.31% in annual output, corresponding to 198 Million Euros. Output losses from additional days of colder temperatures are for the most part limited for this region; offsetting the majority of the losses seen in Central Europe. Some negative influences remain, however, where each additional day below -5°C, relative to the reference, corresponds to an average output loss of 0.761%, or 115 Million Euros. Notably, almost all significant fluctuations from the baseline are derived from temperature change's impact on capital and labor factors rather than TFP.

In conclusion, Europe suffers significant losses, on average 0.266% of annual output, 116 Million Euros, following each additional day of max temperature being above 30°C rather than between 15-20°C. Movement from the 15-20°C reference point to a lower, but still positive, temperature is also associated with significant output losses. After examining subregional heterogeneous treatment effects in the sample, it is evident that the impacts of temperature changes differ across different parts of Europe.

The Western subregion benefits the most from the reallocation from the reference to additional hot temperature days, averaging an output increase of 3.521% (2.03 Billion Euros) for each additional day above 30°C. On the contrary, the Northern and Eastern subregions suffer the most, showing losses corresponding to 2.32 Billion and 198 Million Euros, respectively. These two subregions are however relatively unaffected by colder temperatures and gain some smaller output advantages from an increased annual frequency of days with low max temperature. The Southern region seems to stem the greatest benefit from extra days in the coldest temperature bin, generating an increase in average annual output of 1.04%. Contrarily, Central and Western Europe suffer the most, experiencing an average annual output loss of 1.960% following the introduction of one additional day below -5°C. The drivers for these different responses to temperature for firm production across subregions seem to mainly be losses and gains in capital and labor factors, rather than changes in TFP. This implies that factor reallocation might be an important tool for European firms to mitigate losses caused by temperature fluctuations.

3.2. Precipitation

Accumulated precipitation's effect on Europe's firm production is displayed in Table 6. Each additional dry day, with a precipitation level of 0 mm, relative to that day having a precipitation level of up to 10 mm, is significantly reducing annual production output by 0.039% on average, corresponding to 17 Million Euros. Increased frequency of high daily precipitation levels, more than 20 mm, is exhibiting a negative impact on production output, however not statistically different from zero. Furthermore, changes in daily precipitation levels do not seem to have any significant influence on either labor or TFP. However, capital demonstrates, just as with max temperature, an almost inverse linear relationship. This relationship corresponds to average capital losses of up to 0.663% for each additional day with more than 20 mm precipitation, relative to up to 10 mm. To conclude, Europe seems to suffer larger output losses from additional dry days than from additional days with excessive precipitation levels, and this seems to be driven mainly by variations in the capital factor.

This conclusion, however, does not necessarily hold true for all parts of the sample. The findings might be influenced by subregional differences, potentially contradicting each other. The examination of heterogeneous treatment effects for precipitation across subregions is examined in Tables 11-14. The upper section of these displays the effects for Central Europe, which serve as the baseline. The Central subregion shows similar patterns as Europe as a whole: an average output loss of 0.952%, notably larger than for Europe, from each additional dry day, relative to the up to 10 mm reference. This corresponds to losses of 517 Million Euros, which seem to be driven by, in contrast to the entirety of Europe, losses in both capital and labor factors.

For Northern Europe, Table 11, the output losses associated with additional days with 0 mm precipitation, relative to those days having precipitation levels of up to 10 mm, are insignificantly different from those seen in Central Europe. However, the North is experiencing significant output gains from increased frequency of days with high precipitation, where each additional day with 10-20 mm, relative to the reference, is associated with an average annual output gain of 3.803%, compared to the Central subregion. Additionally, each extra day with more than 20 mm of precipitation, relative to the reference, corresponds to an average 5.391% increase in output, relative to Central Europe. These influences seem to be driven mainly by improved capital, and partly TFP.

The Southern region, displayed in Table 12, shows, similarly to Northern Europe, output benefits from high precipitation levels. Each additional day with accumulated precipitation above 20 mm, rather than the up to 10 mm reference, is associated with average gains of 5.769% in annual output, relative to the effect seen in the Central subregion. These gains are seemingly driven by both higher capital and labor, somewhat different from the North's capital and TFP improvements. The South experiences further positive effects from additional dry days relative to the reference, averaging a 0.046% increase in annual output, translating to 20 Million Euros. This seems to be channeled mainly through an improved labor factor.

Western Europe is depicted in Table 13. It is, similar to the Northern and Southern subregions, showing significantly strong positive influences from additional days with high precipitation levels, relative to the Central region. Each additional day with above 20 mm precipitation, relative to the reference, generates an average gain of 6.204% in annual output. This is, again, mainly channeled through positive impacts in capital and labor factors, rather than improved TFP. Aside from these gains, the West is not showing any other significantly different responses compared to the Central baseline. Likewise, the Eastern subregion, seen in Table 14, is experiencing similar impacts from changes in precipitation level frequency as Central Europe. The estimates for Eastern Europe are not providing support that the subregion is, in terms of output, suffering any greater or lesser economic consequences than the baseline.

To summarize the effects of precipitation on production output and its corresponding channeling parameters, each additional dry day is reducing European annual output by 0.039% on average, relative to that day having precipitation levels of up to 10 mm. This corresponds to losses of 17 Million Euros. The pattern of losses is further shown to also be present in the Central, Eastern, Western, and Northern subregions of Europe, with all of them being relatively evenly and negatively affected by additional dry days. From this, the main losses associated with precipitation for Europe as a whole seem to stem from the lack of rainfall.

For the highest bin, all subregions besides the East and Central are exhibiting output gains of notably high magnitudes from additional days with more than 20 mm, rather than up to 10 mm. These large estimates provide some contradictory results when comparing the subregional aggregate findings with Europe as a whole. This could be driven, at least partly, by having a limited amount of observations in the highest bin, thus providing somewhat noisy estimates. Displaying the number of observations does show some limitations, especially for Southern and Eastern Europe.

Table 4: Days Above 20 mm Per Subregion

Subregion	>20 mm Days
North	8362
South	916
West	3259
East	1359
Central	4900

Table 4: The number of observations of daily accumulated precipitation above 20 mm for all NUTS 2 regions included in the final sample within each European subregion, for the time period 2000-2020. Data source: Copernicus, Eurostat, and The United Nations Geoscheme Classification.

The estimates still provide some valuable insights about the impact high precipitation levels have on regional production output and related parameters: there are benefits from increased rainfall in certain subregions. However, some caution should be taken when using this sample to generalize the magnitude of the highest precipitation bin estimates.

3.3. Lagged Weather

Examining the lagged weather model (Eq.3) for max temperature in Table 15 shows some lagging effects for temperature's negative impact on firm production. Thereby indicating that the accumulated impact potentially could be higher than concluded in the aforementioned analysis. For the middle-range bins, temperatures from -5℃ to 15℃, effects from previous year's temperature persist. The magnitudes of these remaining influences are however relatively limited. For the highest temperature range, above 30℃, the extent of the negative effects seem to somewhat diminish over time, hence being lower in the following, lagging, year than in the current. The impact of having an additional day with temperature above 30℃ last year, rather than 15-20℃, is associated with a lower output loss (averaging 0.151% of annual output) than the continuing effect a year after (averaging 0.255% of annual output). This provides supporting evidence that the negative effect of additional days with high temperatures for European firm production lingers for a time after the shift has taken place, at least for the following year, but is diminishing over time.

3.4. Implications of Results

Europe's output losses of 116 Million Euros for each additional day of high temperature, above 30℃, should provide incentives for European firms to manage their sensitivity to temperature changes and mitigate the associated losses. However, as the heterogeneity analysis suggests, there are significant differences in vulnerability across Europe's subregions. Utilizing regional policy making, where actions and resources can be distributed to the geographical areas needing it the most, could be a way for Europe to manage such mitigation and prevent, at least some, of the economic consequences associated with any future rise in temperature. This becomes even more important if the temperature changes going forward are rightward shifted, as predicted by literature,[101] creating a disproportionate increase in the number of hot days.

As mentioned, the estimates put forward in this work are not mirroring nor are directly applicable to the economic consequences seen by the long-run effects of climate change. Essential interplaying forces that intervene in the applicability of weather patterns to climate change, such as adaptation over time, are long-term ways to deal with the effects seen among these findings. The losses might encourage firms to implement adaptive measures in order to mitigate economic consequences and adjust their production processes to the changing environment. For individual regions, the extent of the production losses will be weighted against the costs of such responses. Therefore, support from the EU's adaptation initiative might be an important tool for European regions to ease such costs and acclimate to negative production responses to temperature changes over time.

Southern Europe seems to experience insignificantly different effects than the Central subregion: positive responses from additional days of temperatures above 30℃. That the South, despite generally being Europe's warmest subregion, benefits from further hot days might be an indication that regions that are accustomed to higher temperatures show signs of adaptation to its effects. Worth to note is that these results solely focus on productional effects and disregard any other societal or humanitarian aspects acting in parallel with changing weather patterns and increased temperatures. This analysis can therefore not state anything definitive about the effects beyond production impacts. However, based on previous literature, it is shown that Southern Europe is heavily affected by extreme weather and vulnerable to climate change.[102] It is therefore possible to reason that, despite showing productional gains, it possibly faces extensive high temperature losses that are not related to firm production.

[101] See section 2.1.
[102] See sections 1. and 1.1.1.

Most of Europe's losses in output are driven by losses in capital and labor, contradicting parts of previous literature carried out in poorer regions of the world.[103] This suggests that there are possibilities for European firms to mitigate the losses associated with fluctuating weather patterns through factor reallocation. Adjusting the distribution between factor inputs could help individual firms or regional production to deal with the economic consequences currently faced. As labor's sensitivity to weather changes seems to be less than capital's, there could be some benefits to gain, or losses to mitigate, by reallocating towards labor rather than capital, to the extent possible for the specific firm/region at hand.

3.5. Future Impact

The scope of these results is limited to the research focus at hand and cannot, without precaution, be directly applied to climate change going forward. Over longer time periods, adaptation to and/or intensification of climate change will be essential for the insights that short-term weather provides for long-term climate change. Over- or underestimation is a clear risk which cannot with ease be circumvented. If intensification of climate change is significantly larger than the adaptation abilities, the losses European firms are experiencing today as a result of weather changes would be even more severe in the long-run. Additionally, the extent to which firms are able to solely adapt in order to fully protect themselves from damages related to weather and climate is not entirely agreed upon in the current field of research.[104]

Nonetheless, to elaborate on the main findings and provide some, although not statistically robust, insights regarding the possible future impact of temperature patterns, the coming century could be looked into. To give an indication of what consequences these effects could have for European firm production going forward, the observed frequency of high temperatures (daily max temperature above 30℃) in 2020 will constitute the current state of temperature distribution. This will be examined relative to the expected frequency in the year 2100 using IPCC's estimation of temperature rise, 3.2℃, adjusted for the current state, 1.1℃ above pre-industrial levels.[105]

A visual representation of the state of distribution of high temperature frequency for the year 2020 across all NUTS 2 regions included in the full sample looks as follows:

[103] See section 1.2.1.
[104] See section 1.2.1.
[105] Hence, the max temperature frequency distribution for each region in 2020 relative to the max temperature frequency distribution for the same region when 2.1℃ is added to the 2020 baseline.

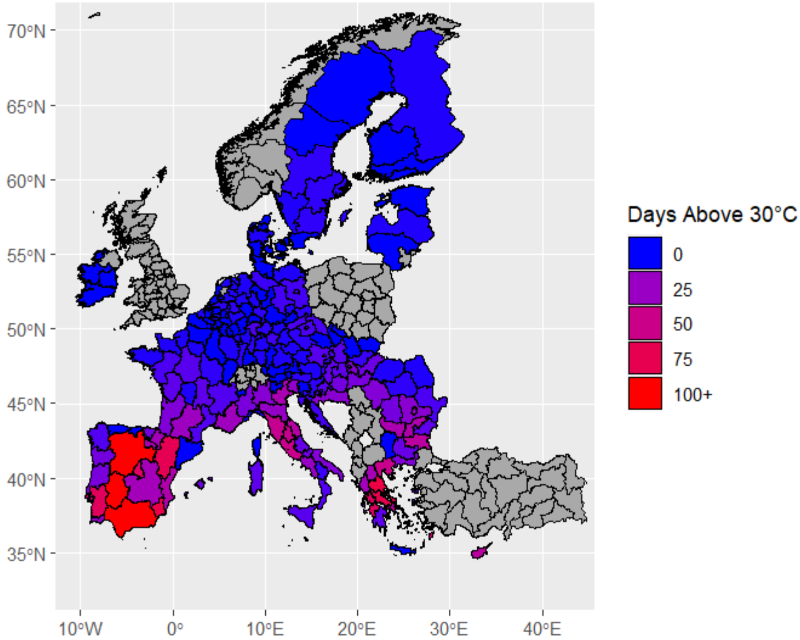

Figure 4: The frequency of days in the highest temperature bin (above 30℃) in 2020 for all NUTS 2 regions included in the final sample. Data source: Copernicus and Eurostat.

From Figure 4, it is evident that the distribution of high temperatures is uneven across the European region. In 2020, the South had the largest share of high temperature days, above 30°C, while the North and Central seem to have had very few. Over larger time spans, vulnerabilities to changes in weather patterns could allude to the level of adaptation implemented thus far. That regions such as Northern Europe are substantially more vulnerable, on average, to hotter days than other regions, such as Southern Europe, might be a reflection of the former experiencing a substantially lower frequency of high temperatures. Thereby, the impacts of such days when they do occur are extensive. Hence, although the North shows substantial losses associated with high temperatures, it is in 2020 experiencing a very limited share of these observations across the year. The South, which is shown to gain production output from additional days of high temperatures, potentially due to historical adaptation, is on the other hand experiencing the largest proportion of these observations.

Looking at the change in frequency of high temperatures as global temperature rises, measured as a temperature increase of 2.1°C from 2020 to 2100, the bin distribution across Europe looks as follows:

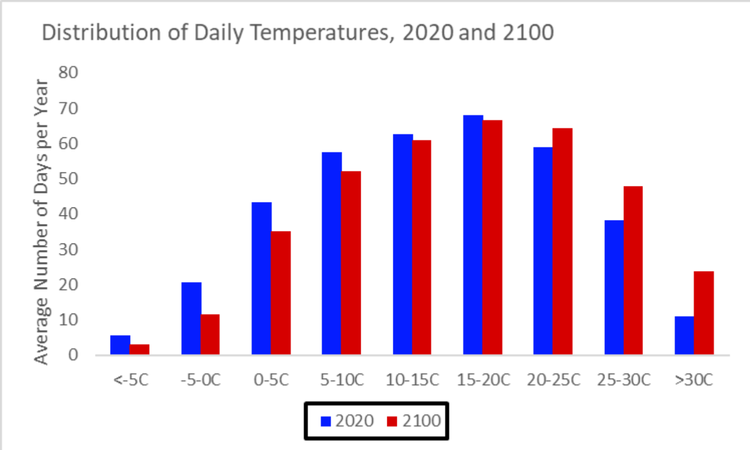

Figure 5: The daily max temperature bin frequency distributions across all NUTS 2 regions included in the final sample for 2020 and 2100, the latter measured as an expected temperature rise of 2.1℃ compared to 2020. Data source: Copernicus, Eurostat, The United Nations, and IPCC.

A visual representation of how such a new distribution of the high temperature frequency would look like in the year 2100, by adding an additional 2.1°C to the 2020 observations, across all NUTS 2 regions included in the full sample looks as follows:

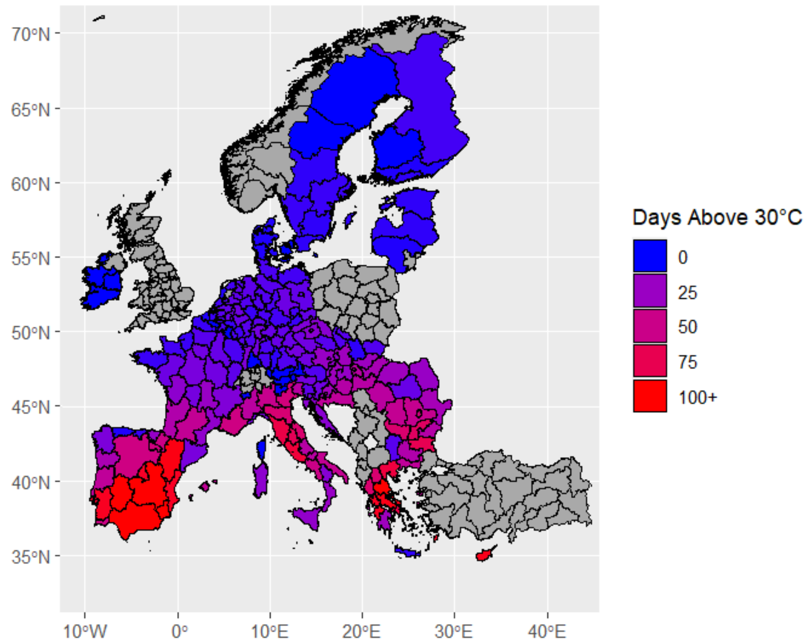

Figure 6: The frequency of days in the highest temperature bin (above 30℃) in 2100 for all NUTS 2 regions included in the final sample, measured as an expected temperature rise of 2.1℃ compared to 2020. Data source: Copernicus, Eurostat, The United Nations, and IPCC.

As temperature rises with time, the frequency of high temperature days will plausibly become more uneven across regions and the differences in exposure larger. For instance, subregions like the East seem to be facing a substantial increase in hot days moving forward, while the North looks, in comparison, relatively unaffected. However, subregions that are sensitive to high temperatures, such as the North, could potentially suffer extensively from only a few additional hot days. While those currently benefiting from cold days will possibly experience less of them moving forward, further widening the gap between the regions.

How this would affect European firms in regards to climate change as a whole, rather than just increased temperatures, cannot confidently be established. Interfering forces of adaptation and/or intensification are limiting the possibility to assess such impacts. If extensive adaptation is set in place in the coming decades, the true impact might be less than the one seen here. However, if firms and production do not manage to adapt to these influences and climate change intensifies over the years, the impacts could be extensively larger, and more damaging, than they are seen to be currently. How adaptation and intensification patterns interplay for Europe, both currently and in the future, will be a crucial determinant of the economic losses associated with climate change and its corresponding effects on weather patterns moving forward.

The conversion from short-term fluctuations to long-run changes in this setting comes with a disclaimer. The method used in this work, assessing the impact of weather on firm production by extracting idiosyncratic local variation only, does remove the ability to accurately estimate the long-term effects corresponding to variation in long-run trends. These are the ones necessary when trying to assess the full impacts of climate change for firms. Whether subregions currently benefiting from high temperatures, such as Southern Europe, and subregions currently losing from high temperatures, such as Northern Europe, will continue to experience the same impacts of fluctuations moving forward, is still unknown. If, when, and how Europe manages to adapt to these influences over time are areas for future research to tackle.

3.6. Conclusions

Europe faces reduced production output from warmer temperatures, where each day with temperature above 30℃, instead of 15-20℃, is generating average annual output losses corresponding to 116 Million Euros. The effects across subregions show distinctions in production consequences and clear heterogeneity at play. For instance, for each additional day above 30℃, relative to the reference, Northern Europe is suffering an average reduction in annual output of 2.32 Billion Euros, whilst Western Europe gains average benefits of 2.03 Billion Euros.

As for precipitation, Europe faces reduced annual output of 0.039%, equating to 17 Million Euros, per additional day of 0 mm precipitation, relative to that day having a precipitation level of up to 10 mm. When examining heterogeneous treatment effects across the sample's subregions, it is evident that most parts of Europe suffer output losses from additional dry days, relative to the reference. Southern Europe is the only outlier, averaging gains of 20 Million Euros for each extra day. Furthermore, some subregions seem to benefit from high levels of precipitation, above 20 mm, while Europe as whole shows no significant effects from further days of extensive rainfall, relative to the reference.

The ability to mitigate losses and adapt on a regional level will be a key determinant of how these influences will change moving forward. As the main channels through which weather fluctuations negatively impact firm production are shown to be capital and labor factors, rather than TFP, factor reallocation is a possible means of such adjustments.

4. Summary

To summarize, this thesis focuses on the impacts of weather fluctuations on European firm production. Similar research has been done in poorer and warmer countries, however no European analyses have been made on the topic. Expanding the current field of research to a colder, previously unexamined environment, as well as using more up-to-date data, the years 2000-2020, creates a unique contribution. To analyze the association between exogenous weather fluctuations and its impact on production, the Cobb-Douglas production function is utilized as the foundation for the economic interpretation. A bin approach is then applied to convert daily regional weather observations into usable annual weather frequencies for max temperature and accumulated precipitation, without assuming any functional form. Each weather bin is then regressed for each region and each year on all four economics variables: output, capital, labor, and TFP.

The findings showed that European output falls, on average, 0.266% for each reallocated day from the reference bin to a day of above 30°C, corresponding to an average annual loss of 116 Million Euros in 2010 values. As for precipitation, Europe's productional output falls by an average of 0.039% for each dry day, relative to the reference. This implies a loss of 17 Million Euros in 2010 values per additional day with 0 mm precipitation. The losses mainly stem from capital and labor factors, with capital being the most sensitive to weather fluctuations.

To examine if these impacts permeate throughout all parts of the sample, heterogeneity tests were done to compare five subregions: Northern, Southern, Western, Eastern, and Central Europe. The corresponding findings showed that the negative influence of high temperature is not applicable to all subregions. The Western parts benefit from the reallocation from the reference bin to hot days, above 30°C, experiencing an output gain of 3.521%, whereas Northern Europe sustained a juxtaposed reduction of 6.465%. For additional cold days, below -5°C, Southern Europe was found to benefit whilst the Central and Western subregions suffered the greatest losses. The impacts of precipitation were more consistent across the subregions, however, providing somewhat noisy estimates for the highest bin.

A lagged model was used to examine if the previous year's weather statistics impact current year losses. It was found that some sustained effects on production output appeared to remain also in the following year. The implications of these combined findings in relation to future climate change cannot be fully established. However, some indicational insights regarding which European subregions that suffer and benefit the most from additional days of high temperatures are provided in this work. How well Europe manages to adapt to the losses associated with weather fluctuations will be a key determination of these effects' future implications.

5. References

Barrios, Salvador, Bertinelli, Luisito, and Stobl, Eric. 2010. "Trends in Rainfall and Economic Growth in Africa: A Neglected Cause of the African Growth Tragedy." *Review of Economics and Statistics* 92 (2): 350–66.

Burke, Paul J., and Leigh, Andrew. 2010. "Do Output Contractions Trigger Democratic Change?" *American Economic Journal: Macroeconomics* 2 (4): 124–57.

Caggese, Andrea, Chiavari, Andrea, Goraya, Sampreet, and Villegas-Sanchez, Carolina. 2022. "Climate Change and Firm Dynamics".

Caselli, Francesco, Esquivel, Gerardo, and Lefort, Fernando. 1996. "Reopening the Convergence Debate: A New Look at Cross-Country Growth Empirics." *Journal of Economic Growth* 1 (3): 363–89.

Climate-ADAPT. n.d. 'Country profiles'. The European Commission and the European Environment Agency. Accessed on October 29 2022. <https://climate-adapt.eea.europa.eu/#t-countries>

Climate-ADAPT. n.d. *EU Adaptation Strategy A new EU adaptation strategy*. The European Commission and the European Environment Agency. Accessed on October 30 2022. <https://climate-adapt.eea.europa.eu/en/eu-adaptation-policy/strategy>

Coi, Giovanna and Mathiesen, Karl. 2021. *The death toll of Europe's heat wave*. Politico. Accessed on September 22 2022. <https://www.politico.eu/article/europe-mediterranean-heatwaves-excess-deaths-climate-change-cop26-glasgow-ipcc/>

Dell, Melissa, Jones, Benjamin F., and Olken, Benjamin A. 2009. "Temperature and Income: Reconciling New Cross-Sectional and Panel Estimates." *American Economic Review* 99 (2): 198–204.

Dell, Melissa, Jones, Benjamin F., and Olken, Benjamin A. 2012. "Temperature Shocks and Economic Growth: Evidence from the Last Half Century." *American Economic Journal: Macroeconomics* 4 (3): 66–95.

Dell, Melissa, Jones, Benjamin F., and Olken, Benjamin A. 2014. "What Do We Learn from the Weather? The New Climate–Economy Literature." *Journal of Economic Literature* 52 (3): 740–798.

Destatis Statistisches Bundesamt. n.d. *NUTS classification The hierarchical categorisation of EU territories and regions*. The Federal Statistical Office and Eurostat. Accessed on October 16 2022. <https://www.destatis.de/Europa/EN/Methods/Classifications/OverviewClassification_NUTS.html>

European Environment Information and Observation Network. 2022. *Economic losses from climate-related extremes in Europe*. European Environment Agency. Accessed on November 6 2022. <https://www.eea.europa.eu/ims/economic-losses-from-climate-related>

Eurostat. 2020. *Correspondence between the NUTS levels and the national administrative units*. The European Union. Accessed on November 20 2022. <https://ec.europa.eu/eurostat/web/nuts/national-structures>

Eurostat. n.d. 'NUTS - Nomenclature of territorial units for statistics - Background'. The European Union. Accessed on October 14 2022. <https://ec.europa.eu/eurostat/web/nuts/background>

Eurostat. n.d. 'NUTS - Nomenclature of territorial units for statistics - History of NUTS'. The European Union. Accessed on October 14 2022. <https://ec.europa.eu/eurostat/web/nuts/history>

Eurostat. n.d. 'Regions - Background'. The European Union. Accessed on October 14 2022. <https://ec.europa.eu/eurostat/web/regions/background>

Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D.W., Haywood, J., Lean, J., Lowe, D.C., Myhre, G., Myhre, J., Prinn, R., Raga, G., Schulz, M. and Van Dorland, R. 2007: Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., and Miller, H.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Harrasova, J. and G, Roy. (Ed.) (2020). Estimating the elasticity of substitution between capital and labour. *Fraser of Allander Economic Commentary*44 (4).

Hidalgo, F. Daniel, Naidu, Suresh, Nichter, Simeon, and Richardson, Neal. 2010. "Economic Determinants of Land Invasions." *Review of Economics and Statistics*92 (3): 505–23.

Hsiang, Solomon M. 2010. "Temperatures and Cyclones Strongly Associated with Economic Production in the Caribbean and Central America." *Proceedings of the National Academy of Sciences*107(35): 15367–72.

Igini, Martina. 2022. *The Tipping Points of Climate Change: How Will Our World Change?* EO. Accessed on November 12 2022. <https://earth.org/tipping-points-of-climate-change/>

Jones, Benjamin F., and Olken, Benjamin A. 2010. "Climate Shocks and Exports." *American Economic Review* 100 (2): 454–59.

Kalantzis, Fotios, Dominguez, Sofia and Amat, Adriano. 2021. *European firms and climate change 2020/2021: Evidence from the EIB Investment Survey.* European Investment Bank. https://www.eib.org/attachments/publications/eibis_2020_report_on_climate_change_en.pdf

Lai, Olivia. 2022. *IPCC Climate Report Warns 'It's Now or Never' to Limit Global Warming As 1.5C Becomes More Out of Reach.* EO. Accessed on October 26 2022. <https://earth.org/ipcc-climate-report-warns-its-now-or-never-to-limit-global-warming-as-1-5c-becomes-more-out-of-reach/>

Lennkh, Alvise, Vasse, Thibault, Barisone, Dr Giacomo and Curtin, Matthew. 2021. *Extreme climate events in Europe: rising economic losses can lead to greater sovereign ratings divergence.* Scope Ratings. https://www.scopegroup.com/dam/jcr:eb50a1cd-7bcd-46db-a2fe-80fa9b1d76da/Scope%20Ratings_Extreme%20climate%20events_2021%20Nov.pdf

Mercy Corps. 2021. *The facts: How climate change affects people living in poverty.* Accessed on October 22 2022. <https://europe.mercycorps.org/en-gb/blog/climate-change-poverty>

NASA/GISS. 2021. *Global Temperature.* National Aeronautics and Space Administration. Accessed on November 27 2022. <https://climate.nasa.gov/>

Pearce, Rosamund, Prater, Tom (upd.) and Goodman, Jee (upd.). 2022. *Mapped: How climate change affects extreme weather around the world.* Carbon Brief. Accessed on 2 November 2022. <https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world/>

Schlenker, Wolfram, and Roberts, Michael J. 2009. "Nonlinear Temperature Effects Indicate Severe Damages to U.S. Crop Yields under Climate Change." *Proceedings of the National Academy of Sciences*106 (37): 15594–98.

Shvili, Jason. 2021. *Regions Of Europe.* WorldAtlas. Accessed on November 5 2022. <https://www.worldatlas.com/articles/the-four-european-regions-as-defined-by-the-united-nations-geoscheme-for-europe.html#h_49954474660316207890957666>

Somanathan, E., Somanathan, Rohini, Sudarshan, Anant and Tewari, Meenu. 2021. "The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing." *Journal of Political Economy*129 (6): 1667-1945.

The Council of the European Union. 2022. *Infographic - Climate change costs lives and money.* The European Union. Accessed on November 30 2022. <https://www.consilium.europa.eu/en/infographics/climate-costs/>

The United Nations. 2022. *For a livable climate: Net-zero commitments must be backed by credible action.* Accessed on October 24 2022. <https://www.un.org/en/climatechange/net-zero-coalition>

The World Bank. *Consumer price index (2010 = 100) - European Union.* 2022. The World Bank Group. Accessed on November 28 2022. <https://data.worldbank.org/indicator/FP.CPI.TOTL?end=2021&locations=EU&name_desc=true&start=2000&view=chart>

UN Environment Programme. 2022. *As heatwaves blanket Europe, cities turn to nature for solutions.* The United Nations. Accessed on October 23 2022. <https://www.unep.org/news-and-stories/story/heatwaves-blanket-europe-cities-turn-nature-solutions>

UN News. 2021. *UN climate report a 'red alert' for the planet: Guterres*. The United Nations. Accessed on November 4 2022. <https://news.un.org/en/story/2021/02/1085812>

Zhang, Peng, Zhang, Junjie, Deschênes, Olivier and Meng, Kyle. 2016. "Temperature Effects on Productivity and Factor Reallocation: Evidence from a Half Million Chinese Manufacturing Plants". *Journal of Environmental Economicsand Management* 88: 1-17.

6. Appendix A - Figures

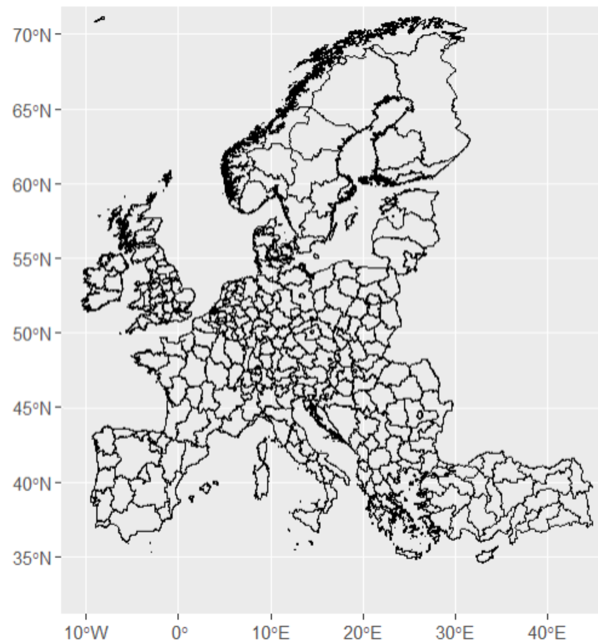

Figure A: The borders of the 372 NUTS 2 regions in accordance with the 2021 classification. Data source: Eurostat.

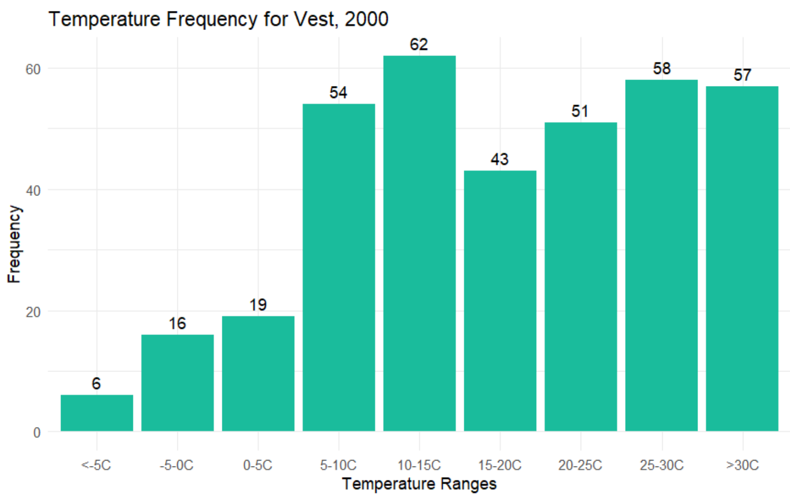

Figure B: An example of the bin construction of daily max temperature for one of the NUTS 2 regions, Vest (Romania), in 2000. Data source: Copernicus and Eurostat.

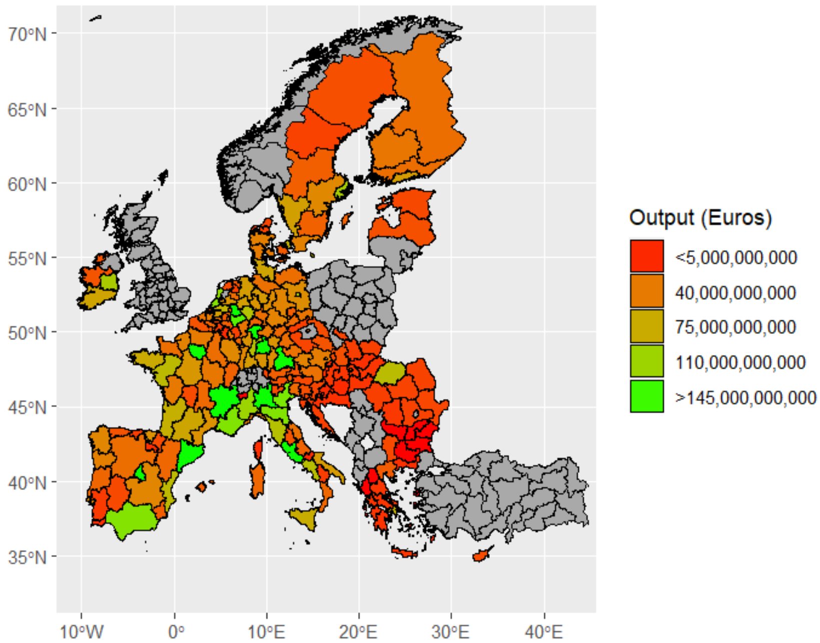

Figure C: Average annual production output per NUTS 2 region included in the final sample, for the time period 2000-2020. Data source: Eurostat.

Table 5: Effect of Temperature on Output, Capital, Labor, and TFP

	Dependent Variables			
	Output	Labor	Capital	TFP
	(1)	(2)	(3)	(4)
<-5 (°C)	−0.078	0.039	0.240**	−0.048
-5-0 (°C)	0.037	0.018	0.172**	−0.022
0-5 (°C)	−0.080*	−0.009	0.015	−0.029
5-10 (°C)	−0.156***	0.005	−0.082	−0.026
10-15 (°C)	−0.053**	0.002	−0.064	0.011
20-25 (°C)	0.001	−0.029**	−0.114***	0.016
25-30 (°C)	−0.141***	−0.013	−0.201***	−0.001
>30 (°C)	−0.266***	−0.025	−0.283***	0.024
Sum Precipitation	−0.00004**	0.00000	−0.0001***	−0.00002*
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 5: Regression output for max temperature on output, labor, capital, and TFP. Standard errors are excluded to save space. Significance levels correspond to 1% (***), 5% (**) and 10% (*). Data source: Copernicus and Eurostat.

Table 6: Effect of Precipitation on Output, Capital, Labor, and TFP

	Dependent Variables			
	Output	Labor	Capital	TFP
	(1)	(2)	(3)	(4)
0 mm	−0.039***	0.008	−0.042*	0.0005
10-20 mm	−0.105*	0.015	−0.297***	−0.009
>20 mm	−0.131	−0.037	−0.663***	0.023
Mean Max Temperature	−0.021***	−0.005**	−0.043***	0.005
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 6: Regression output for accumulated precipitation on output, labor, capital, and TFP. Standard errors are excluded to save space. Significance levels correspond to 1% (***), 5% (**) and 10% (*). Data source: Copernicus and Eurostat.

Table 7: Effect of Northern Region Temperature on Output, Capital, Labor, and TFP

	Dependent Variables			
	Output	Labor	Capital	TFP
	(1)	(2)	(3)	(4)
North	0.228	2.652	0.601	-1.589^{**}
South	-6.004^{***}	-4.488^{***}	-4.794^{***}	-2.100^{***}
West	-3.376^{***}	-2.193	-2.071	-1.086
East	-2.771^{***}	-3.322^{**}	-2.698^{*}	-0.867
<-5 (°C)	-1.960^{***}	-1.187^{*}	-1.224^{*}	-0.729
-5-0 (°C)	-1.674^{***}	-1.618^{***}	-1.424^{***}	-0.420
0-5 (°C)	-1.209^{***}	-0.937^{***}	-0.891^{**}	-0.380
5-10 (°C)	-0.958^{***}	-0.762^{**}	-0.734^{**}	-0.589
10-15 (°C)	-1.081^{***}	-0.719	-0.803^{*}	-0.713^{***}
20-25 (°C)	-0.374	0.101	-0.080	-0.534^{**}
25-30 (°C)	-1.549^{***}	-1.465^{*}	-1.230	-0.997^{***}
>30 (°C)	1.820^{**}	1.839^{**}	1.640^{**}	-0.187
Sum Precipitation	-0.0002^{***}	-0.0002	-0.0003	0.0001
<-5 (°C) X North	1.059^{**}	0.099	0.549	1.232^{**}
-5-0 (°C) X North	-0.214	-0.704	-0.458	0.023
0-5 (°C) X North	-0.605	-1.430	-0.799	0.306
5-10 (°C) X North	-0.404	-1.967^{**}	-0.273	0.473
10-15 (°C) X North	-0.159	-0.899	-0.143	0.817^{**}
20-25 (°C) X North	0.381	0.302	0.291	0.491^{*}
25-30 (°C) X North	1.282^{*}	1.898^{*}	0.970	1.213^{***}
>30 (°C) X North	-8.285^{*}	-6.124^{**}	-9.536^{***}	1.436

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 7: Northern subregional regression output for max temperature on output, labor, capital and TFP. The Central subregion serves as the baseline. Standard errors are excluded to save space. Significance levels correspond to 1% (***), 5% (**) and 10% (*). Data source: Copernicus, Eurostat, and The United Nations Geoscheme classification.

Table 8: Effect of Southern Region Temperature on Output, Capital, Labor, and TFP

	Dependent Variables			
	Output	Labor	Capital	TFP
	(1)	(2)	(3)	(4)
North	0.228	2.652	0.601	−1.589**
South	−6.004***	−4.488***	−4.794***	−2.100***
West	−3.376***	−2.193	−2.071	−1.086
East	−2.771***	−3.322**	−2.698*	−0.867
<-5 (°C)	−1.960***	−1.187*	−1.224*	−0.729
-5-0 (°C)	−1.674***	−1.618***	−1.424***	−0.420
0-5 (°C)	−1.209***	−0.937***	−0.891**	−0.380
5-10 (°C)	−0.958***	−0.762**	−0.734**	−0.589
10-15 (°C)	−1.081***	−0.719	−0.803*	−0.713***
20-25 (°C)	−0.374	0.101	−0.080	−0.534**
25-30 (°C)	−1.549***	−1.465*	−1.230	−0.997***
>30 (°C)	1.820**	1.839**	1.640**	−0.187
Sum Precipitation	−0.0002***	−0.0002	−0.0003	0.0001
<-5 (°C) X South	3.000***	2.069**	1.886*	1.144*
-5-0 (°C) X South	0.561	0.460	0.192	0.727*
0-5 (°C) X South	1.593***	1.330*	1.218	0.214
5-10 (°C) X South	2.257***	1.906***	2.033***	1.013***
10-15 (°C) X South	2.348***	1.794**	2.026**	0.886***
20-25 (°C) X South	0.554	0.106	−0.001	0.673***
25-30 (°C) X South	2.212***	2.291**	1.742	1.037***
>30 (°C) X South	−0.987	−0.998	−0.882	−0.060
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 8: Southern subregional regression output for max temperature on output, labor, capital and TFP. The Central subregion serves as the baseline. Standard errors are excluded to save space. Significance levels correspond to 1% (***), 5% (**) and 10% (*). Data source: Copernicus, Eurostat, and The United Nations Geoscheme classification.

Table 9: Effect of Western Region Temperature on Output, Capital, Labor, and TFP

	Dependent Variables			
	Output	Labor	Capital	TFP
	(1)	(2)	(3)	(4)
North	0.228	2.652	0.601	−1.589**
South	−6.004***	−4.488***	−4.794***	−2.100***
West	−3.376***	−2.193	−2.071	−1.086
East	−2.771***	−3.322**	−2.698*	−0.867
<-5 (°C)	−1.960***	−1.187*	−1.224*	−0.729
-5-0 (°C)	−1.674***	−1.618***	−1.424***	−0.420
0-5 (°C)	−1.209***	−0.937***	−0.891**	−0.380
5-10 (°C)	−0.958***	−0.762**	−0.734**	−0.589
10-15 (°C)	−1.081***	−0.719	−0.803*	−0.713***
20-25 (°C)	−0.374	0.101	−0.080	−0.534**
25-30 (°C)	−1.549***	−1.465*	−1.230	−0.997***
>30 (°C)	1.820**	1.839**	1.640**	−0.187
Sum Precipitation	−0.0002***	−0.0002	−0.0003	0.0001
<-5 (°C) X West	1.422	1.540	1.250	0.680
-5-0 (°C) X West	1.020*	0.645	0.311	0.272
0-5 (°C) X West	0.354	−0.042	−0.048	0.234
5-10 (°C) X West	0.843**	0.356	0.417	0.218
10-15 (°C) X West	0.997**	0.780	0.723	0.482*
20-25 (°C) X West	1.599***	0.827	1.132	0.544*
25-30 (°C) X West	0.895	0.884	0.389	0.649*
>30 (°C) X West	1.701*	1.066	1.367	0.193

Note: *p<0.1; **p<0.05; ***p<0.01

Table 9: Western subregional regression output for max temperature on output, labor, capital and TFP. The Central subregion serves as the baseline. Standard errors are excluded to save space. Significance levels correspond to 1% (***), 5% (**) and 10% (*). Data source: Copernicus, Eurostat, and The United Nations Geoscheme classification.

Table 10: Effect of Eastern Region Temperature on Output, Capital, Labor, and TFP

	Dependent Variables			
	Output	Labor	Capital	TFP
	(1)	(2)	(3)	(4)
North	0.228	2.652	0.601	-1.589^{**}
South	-6.004^{***}	-4.488^{***}	-4.794^{***}	-2.100^{***}
West	-3.376^{***}	-2.193	-2.071	-1.086
East	-2.771^{***}	-3.322^{**}	-2.698^{*}	-0.867
<-5 (°C)	-1.960^{***}	-1.187^{*}	-1.224^{*}	-0.729
-5-0 (°C)	-1.674^{***}	-1.618^{***}	-1.424^{***}	-0.420
0-5 (°C)	-1.209^{***}	-0.937^{***}	-0.891^{**}	-0.380
5-10 (°C)	-0.958^{***}	-0.762^{**}	-0.734^{**}	-0.589
10-15 (°C)	-1.081^{***}	-0.719	-0.803^{*}	-0.713^{***}
20-25 (°C)	-0.374	0.101	-0.080	-0.534^{**}
25-30 (°C)	-1.549^{***}	-1.465^{*}	-1.230	-0.997^{***}
>30 (°C)	1.820^{**}	1.839^{**}	1.640^{**}	-0.187
Sum Precipitation	-0.0002^{***}	-0.0002	-0.0003	0.0001
<-5 (°C) X East	1.199^{**}	1.910^{***}	1.070	0.433
-5-0 (°C) X East	1.726^{***}	2.475^{***}	1.929^{***}	-0.049
0-5 (°C) X East	1.046^{***}	1.180^{**}	1.096^{**}	-0.233
5-10 (°C) X East	-0.405	1.072^{***}	0.858^{*}	-0.551
10-15 (°C) X East	0.543	1.164^{*}	0.424	0.562
20-25 (°C) X East	0.929^{*}	0.338	0.190	0.684^{*}
25-30 (°C) X East	0.070	1.760^{*}	-0.303	1.032^{***}
>30 (°C) X East	-3.130^{***}	-1.554^{**}	-2.518^{***}	0.112

Note: *p<0.1; **p<0.05; ***p<0.01

Table 10: Eastern subregional regression output for max temperature on output, labor, capital and TFP. The Central subregion serves as the baseline. Standard errors are excluded to save space. Significance levels correspond to 1% (***), 5% (**) and 10% (*). Data source: Copernicus, Eurostat, and The United Nations Geoscheme classification.

.

Table 11: Effect of Northern Region Precipitation on Output, Capital, Labor, and TFP

	Dependent Variables			
	Output	Labor	Capital	TFP
	(1)	(2)	(3)	(4)
North	−3.093**	−0.622	−1.883	−0.290
South	−3.825***	−3.210***	−2.887**	−0.469
West	−2.703*	−2.604*	−1.952	−0.532
East	0.821	−1.300	0.846	−2.449***
0 mm	−0.952***	−0.783***	−0.692**	−0.208
10-20 mm	−1.189	−1.330	−0.941	−0.189
>20 mm	−2.223	−2.151	−2.179	0.021
Mean Max Temperature	0.049*	0.063**	0.033	−0.021**
0 mm X North	0.926	0.140	0.452	0.101
10-20 mm X North	3.803***	0.162	3.377**	−0.497
>20 mm X North	5.391**	0.848	6.870**	4.438*

Note: *p<0.1; **p<0.05; ***p<0.01

Table 11: Northern subregional regression output for accumulated precipitation on output, labor, capital and TFP. The Central subregion serves as the baseline. Standard errors are excluded to save space. Significance levels correspond to 1% (***), 5% (**) and 10% (*). Data Source: Copernicus, Eurostat, and The United Nations Geoscheme classification.

Table 12: Effect of Southern Region Precipitation on Output, Capital, Labor, and TFP

	Dependent Variables			
	Output	Labor	Capital	TFP
	(1)	(2)	(3)	(4)
North	-3.093^{**}	-0.622	-1.883	-0.290
South	-3.825^{***}	-3.210^{***}	-2.887^{**}	-0.469
West	-2.703^{*}	-2.604^{*}	-1.952	-0.532
East	0.821	-1.300	0.846	-2.449^{***}
0 mm	-0.952^{***}	-0.783^{***}	-0.692^{**}	-0.208
10-20 mm	-1.189	-1.330	-0.941	-0.189
>20 mm	-2.223	-2.151	-2.179	0.021
Mean Max Temperature	0.049^{*}	0.063^{**}	0.033	-0.021^{**}
0 mm X South	0.998^{*}	0.872^{*}	0.711	0.182
10-20 mm X South	0.953	2.130^{*}	0.619	0.471
>20 mm X South	5.769^{***}	4.201^{**}	4.171^{*}	0.869

Note: *p<0.1; **p<0.05; ***p<0.01

Table 12: Southern subregional regression output for accumulated precipitation on output, labor, capital and TFP. The Central subregion serves as the baseline. Standard errors are excluded to save space. Significance levels correspond to 1% (***), 5% (**) and 10% (*). Data Source: Copernicus, Eurostat, and The United Nations Geoscheme classification.

Table 13: Effect of Western Region Precipitation on Output, Capital, Labor, and TFP

	Dependent Variables			
	Output	Labor	Capital	TFP
	(1)	(2)	(3)	(4)
North	-3.093^{**}	-0.622	-1.883	-0.290
South	-3.825^{***}	-3.210^{***}	-2.887^{**}	-0.469
West	-2.703^{*}	-2.604^{*}	-1.952	-0.532
East	0.821	-1.300	0.846	-2.449^{***}
0 mm	-0.952^{***}	-0.783^{***}	-0.692^{**}	-0.208
10-20 mm	-1.189	-1.330	-0.941	-0.189
>20 mm	-2.223	-2.151	-2.179	0.021
Mean Max Temperature	0.049^{*}	0.063^{**}	0.033	-0.021^{**}
0 mm X West	0.984	0.934^{*}	0.773	0.239
10-20 mm X West	-0.148	-0.102	-0.887	0.621
>20 mm X West	6.204^{*}	5.338^{*}	5.372^{*}	-1.025

Note: *p<0.1; **p<0.05; ***p<0.01

Table 13: Western subregional regression output for accumulated precipitation on output, labor, capital and TFP. The Central subregion serves as the baseline. Standard errors are excluded to save space. Significance levels correspond to 1% (***), 5% (**) and 10% (*). Data Source: Copernicus, Eurostat, and The United Nations Geoscheme classification.

Table 14: Effect of Eastern Region Precipitation on Output, Capital, Labor, and TFP

	Dependent Variables			
	Output	Labor	Capital	TFP
	(1)	(2)	(3)	(4)
North	-3.093^{**}	-0.622	-1.883	-0.290
South	-3.825^{***}	-3.210^{***}	-2.887^{**}	-0.469
West	-2.703^{*}	-2.604^{*}	-1.952	-0.532
East	0.821	-1.300	0.846	-2.449^{***}
0 mm	-0.952^{***}	-0.783^{***}	-0.692^{**}	-0.208
10-20 mm	-1.189	-1.330	-0.941	-0.189
>20 mm	-2.223	-2.151	-2.179	0.021
Mean Max Temperature	0.049^{*}	0.063^{**}	0.033	-0.021^{**}
0 mm X East	-0.815	0.439	-0.787	0.857^{***}
10-20 mm X East	-0.392	1.531	-1.058	1.025
>20 mm X East	6.441	1.420	9.482^{**}	1.822
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 14: Eastern subregional regression output for accumulated precipitation on output, labor, capital and TFP. The Central subregion serves as the baseline. Standard errors are excluded to save space. Significance levels correspond to 1% (***), 5% (**) and 10% (*). Data Source: Copernicus, Eurostat, and The United Nations Geoscheme classification.

Table 15: Effect of Lagged Temperature on Output, Capital, Labor, and TFP

	Dependent Variables			
	Output	Labor	Capital	TFP
	(1)	(2)	(3)	(4)
<-5 (°C)	−0.075	0.034	0.221	−0.054
-5-0 (°C)	0.046	0.019	0.171	−0.028
0-5 (°C)	−0.077	−0.008	0.015	−0.033
5-10 (°C)	−0.154**	0.003	−0.081	−0.026
10-15 (°C)	−0.053	0.0004	−0.060	0.009
20-25 (°C)	−0.002	−0.028*	−0.115*	0.013
25-30 (°C)	−0.140***	−0.013	−0.201***	−0.0004
>30 (°C)	−0.255***	−0.025	−0.277**	0.024
<-5 (°C) Lagged	0.003	0.035*	0.142	0.023
-5-0 (°C) Lagged	−0.080**	−0.002	−0.004	0.028
0-5 (°C) Lagged	−0.071**	−0.019	−0.033	0.036
5-10 (°C) Lagged	−0.047**	0.011	−0.026	−0.007
10-15 (°C) Lagged	−0.046***	−0.004	−0.042	0.016
20-25 (°C) Lagged	0.033	−0.008	0.027	0.039***
25-30 (°C) Lagged	−0.027	0.007	−0.005	0.052***
>30 (°C) Lagged	−0.151***	−0.012	−0.126***	−0.007
Sum Precipitation	−0.00004*	0.00000	−0.0001**	−0.00001
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 15: Lagged regression output for max temperature at year t and t-1 on output, labor, capital, and TFP. Standard errors are excluded to save space. Significance levels correspond to 1% (***), 5% (**) and 10% (*). Data source: Copernicus and Eurostat.

7. Appendix B - NUTS 2 Regions

Lists of all included and excluded NUTS 2 regions in the final sample are provided through the following link:

https://docs.google.com/spreadsheets/d/1kbYhOGFCfaXT5Vhs4r89G-mLZi2yVr30/edit?usp=sharing&ouid=105026157213974245330&rtpof=true&sd=true.