24 JUNE 2025 · RESEARCH BULLETIN NO. 132

Climate change, firms and aggregate productivity

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The effects of climate change on aggregate productivity

Climate change is one of the most pressing policy challenges of our time, occupying a central place in both public discourse and economic analysis. Policy debates frequently focus on the trade-off between the near-term costs of reducing carbon emissions and the long-term benefits of mitigating climate change. The seminal contribution by Nordhaus (1977) highlighted the importance of aggregate productivity losses from climate change in shaping this intertemporal trade-off. However, accurately quantifying these losses remains difficult and continues to be a central topic in the academic literature. Despite significant progress, many estimates overlook the role of firms and the barriers that constrain their behaviour in amplifying or mitigating aggregate losses. Bridging this data gap is crucial for designing effective climate policy, especially as governments consider more and more ambitious targets, such as those set out in recent COP summits and the EU Green Deal.

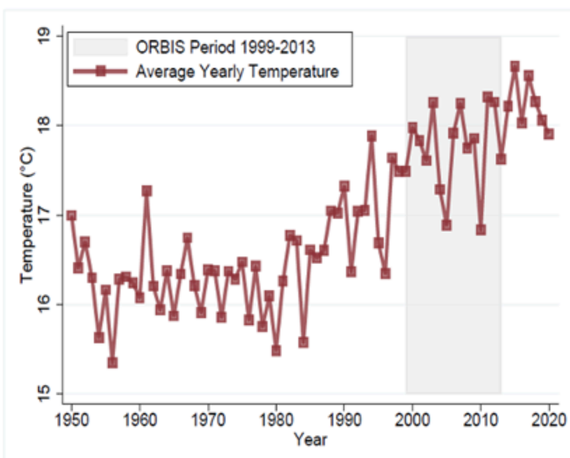
One effect of climate change is the increase in global temperatures driven by rising carbon emissions. This trend imposes direct productivity losses on firms, as extreme heat reduces worker efficiency, raises absenteeism and impairs machinery performance (Heal and Park, 2016; Seppänen et al., 2006; Somanathan et al., 2021). While these direct effects are substantial, there are indirect effects which are equally important but often overlooked. These indirect effects come from the limited ability of firms to adjust inputs efficiently in response to climate shocks. Firm-level frictions, such as high adjustment costs, financial constraints and the inability to substitute labour for capital, can severely restrict this flexibility. For instance, when firms face barriers to scaling down capital inputs, they are forced to keep excess capital during periods of reduced activity. This diminishes its marginal productivity due to decreasing returns. To illustrate how such frictions turn into productivity losses, consider the example of an extreme temperature event that affects half of a country, causing firms there to be non-operational for 20% of the time, resulting in a 20% drop in their output. In a frictionless economy where it costs firms nothing to adjust inputs and firms can operate under constant returns to scale, aggregate productivity would stay the same, as inputs and outputs contract to the same extent. However, if unaffected firms can increase production while affected firms are unable to adjust their input use, the economy experiences a misallocation of resources. The result is a decline in aggregate productivity owing to an indirect effect (i.e. inputs are inefficiently assigned across firms).[2] In the above scenario, this decline would be roughly 10%. The example highlights how firm-level frictions can magnify the overall economic consequences of climate shocks. This is also important for Integrated Assessment Models, which often abstract from microeconomic detail, potentially underestimating the true economic costs of climate change.

In our recent paper (Caggese et al., 2025), we examined both the direct and indirect effects of extreme temperatures on firm performance. We achieved this by combining detailed microdata on Italian firms with high-resolution temperature records from the EU's Copernicus E-OBS dataset. Italy's diverse climatic and economic geography – spanning from Alpine industrial hubs in the North to the warmer, less-industrialised regions in the South – provides an ideal natural laboratory for studying the economic consequences of temperature variation. Figure 1, panel a) illustrates how average maximum temperatures have evolved across Italy, revealing both significant year-on-year volatility and a clear upward trend. Figure 1, panel b) displays the geographical distribution of average annual temperatures in 1999 across very detailed geographic units using the Nomenclature of territorial units for statistics (NUTS), the EU system for subdividing countries into regions for statistical purposes. The wide range of average temperatures, from 0.14°C to 23.82°C, highlights the large differences between regions and confirms how suitable Italy is for the analysis.

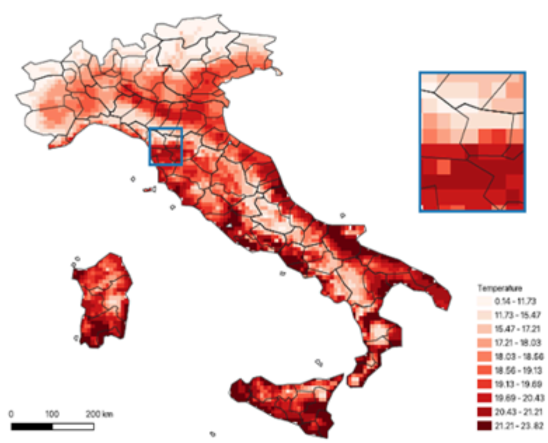
Figure 1

Temperature in Italy

a) Average yearly temperature



b) Average temperature in 1999



Source: Caggese et al. (2025).

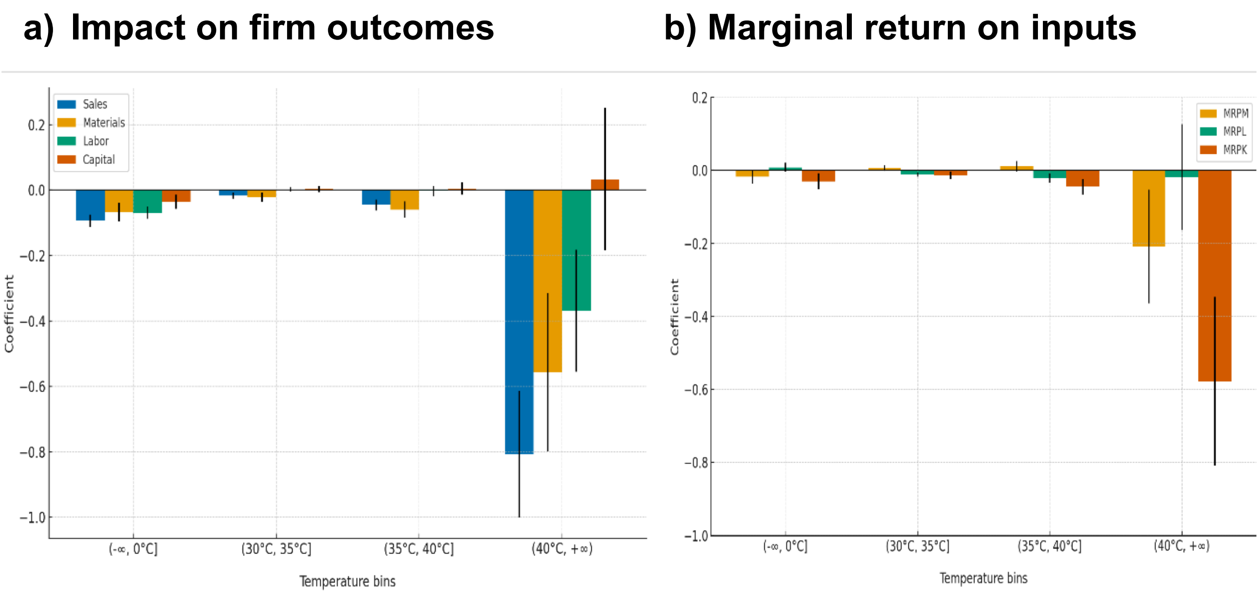
Notes: Panel a) shows the evolution of the average yearly temperature in Italy between 1950 and 2020. The grey shaded area shows the time frame (1999-2013) for which data are available in the Orbis database. Panel b) shows the average temperature across all the grid cells in Italy in 1999. It also plots regional boundaries at the NUTS 3 level.

What is the effect of temperature on firm performance?

Our analysis uncovers a significant direct effect of extreme heat on firm performance. Episodes of very high temperatures reduce sales by approximately 0.8%, with each additional day above 40°C equivalent to nearly two days of lost sales. In response to these conditions, firms substantially reduce labour and material inputs but notably do not adjust their capital usage (Figure 2, panel a). This rigidity is likely driven by high adjustment costs and other firm-level frictions, leading to an inefficient allocation of capital and a decline in its marginal productivity. For example, we find that a factory significantly scales back its production activity during periods of extreme heat. To cope with this reduced output, it cuts down on workers' shifts and temporarily reduces raw material purchases. However, its machinery, cooling systems and physical infrastructure remain unchanged. These capital assets are costly to adjust or relocate, so they sit underused. As a result, the factory's capital is not being deployed efficiently and the return on that investment – its marginal productivity – declines. To illustrate how this inability to reallocate capital contributes to productivity losses, Figure 2, panel b) shows the effect of temperature on the marginal product of different inputs. In a frictionless setting, aggregate productivity rises as inputs flow to firms that can use them the most efficiently, i.e. firms with the highest marginal returns. We also find that the marginal productivity of labour and materials remains relatively stable, reflecting the ability of firms to adjust these inputs flexibly. In contrast, the marginal productivity of capital declines sharply at high temperatures, indicating that firms are unable to shed excess capital when it becomes unproductive. We refer to these inefficiencies in capital use and the associated productivity losses as the indirect effects of temperature shocks.

Figure 2

The effect of temperature on firm outcomes and marginal returns



Source: Caggese et al. (2025)

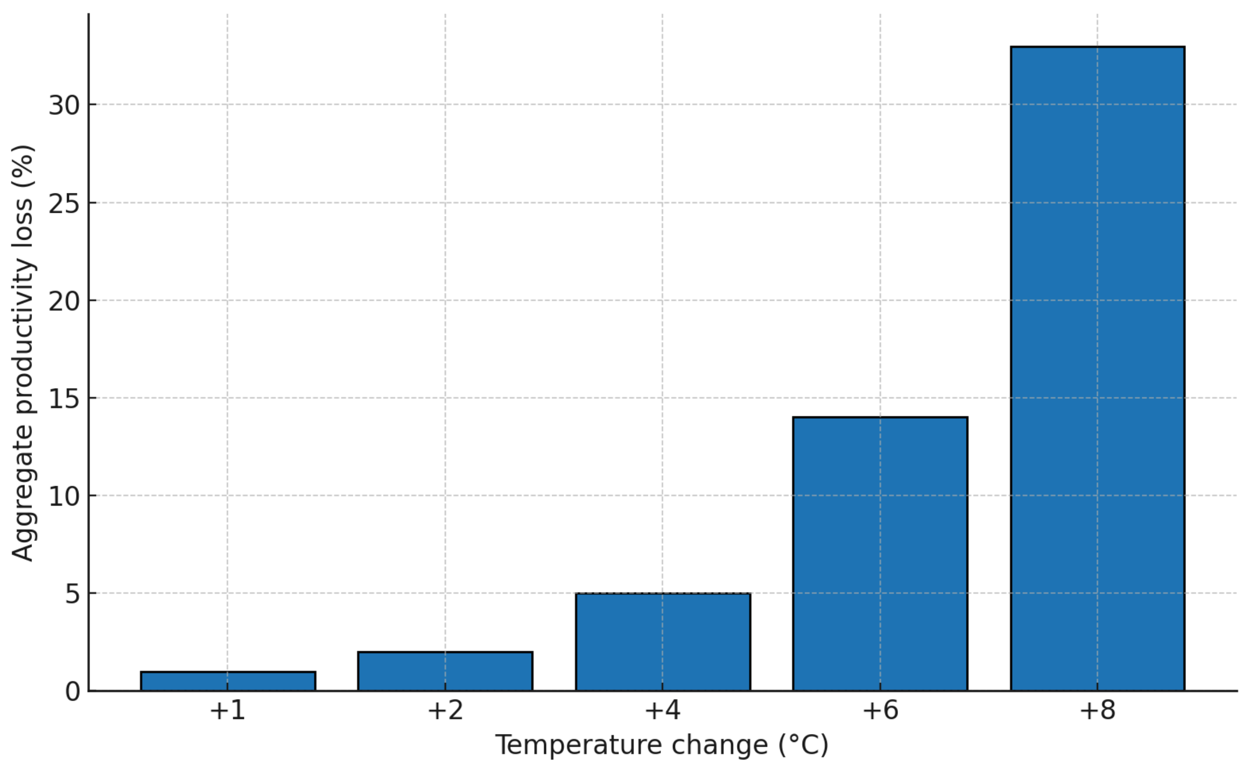
Notes: Daily temperatures are aggregated to the annual level by counting the number of days falling within specific temperature bins. The bins used are: {(−∞, 0°C], (0°C, 30°C], (30°C, 35 °C], (35°C, 40°C], (40°C, +∞)}. We estimate the following equation: $Outcome_{it} = \sum_{\ell} \beta_{\ell} T_{\ell, g(i)t} + \delta Rain_{g(i)t} + \lambda' X_{r(i)t} + \gamma_{s(i)t} + \alpha_i + \varepsilon_{it}$. The coefficient of interest is β_ℓ, which captures the effect of an extra day falling within the temperature bin ℓ relative to the reference temperature bin. Therefore, $\beta_\ell < 0$ implies that the given firm-level outcome declines β_ℓ percent for each extra day that falls within the temperature bin ℓ relative to the reference temperature bin. We set the interval [0°C, 30°C) as the reference temperature bin since it covers the average range of temperature recorded by most NUTS 3 regions. Figure 2 plots the β_ℓ coefficient, the effect on the log of the dependent variable of adding an extra day in the given temperature range. Panel a) shows the effect on the log of sales, expenditure on materials, employee compensation and capital. Panel b) shows the effect on the marginal revenue product of materials (MRPM), marginal revenue product of labour (MRPL) and marginal revenue product of capital (MRPK).

What are the aggregate implications of climate change?

To quantify the aggregate implications of these micro-level direct and indirect effects, we have developed a model that maps estimated firm-level semi-elasticities of sales and input use to temperature changes. To estimate how climate change affects overall productivity, we need to consider three main factors: how firm productivity responds to temperature, how firms' use of inputs like labour and materials changes with temperature and how temperatures are expected to change. We use our empirical results to quantify the first two factors, and we compute counterfactual scenarios of potential temperature increases. This framework allows us to break down aggregate productivity effects into two components: changes driven by efficiency losses within firms and changes arising from misallocation across firms. Our new approach reveals differences compared with previous research. Under a moderate scenario involving a 2°C increase in average annual temperatures, our model predicts a 1.68% decline in aggregate productivity. This decline is more than four times the 0.39% loss that is estimated using a naïve approach, which is a basic method that averages firm-level effects without considering economics factors like allocative distortions. These effects become even more pronounced under an increase of 4°C, with productivity losses rising to approximately 6.81%, which emphasises how climate shocks can have complex effects that can intensify existing problems (Figure 3).

Figure 3

Aggregate productivity losses under different temperature change scenarios



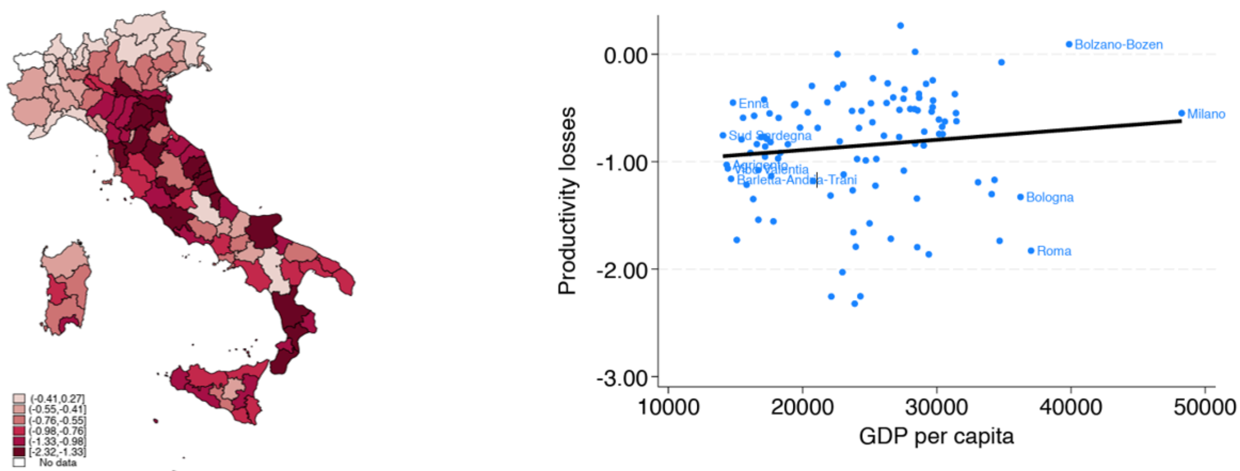
Source: Caggese et al. (2025).

We conclude by examining two scenarios that could either amplify or mitigate the effects of climate change. First, we assess the role of firm-level adaptation. By comparing regions with a long history of exposure to extreme temperatures – where firms are more likely to have already adopted climate-resilient technologies – with regions that have only recently started to experience such temperatures, we find evidence that adaptation can substantially reduce the economic impact of heat shocks. Specifically, the use of climate-mitigating technologies lowers estimated damages by 20-30%. Second, we construct aggregate damage functions at the NUTS 3 level to evaluate the regional distribution of climate-induced productivity losses across Italian provinces. This geographical analysis reveals considerable variation, with effects ranging from mildly positive to severely negative (Figure 4, panel a). Notably, provinces with lower GDP per capita are projected to experience greater temperature increases, suggesting that climate change is likely to make existing regional disparities worse. Figure 4, panel b) plots projected productivity losses against regional GDP per capita, revealing that wealthier regions tend to incur smaller productivity losses, while poorer regions are more severely affected.

Figure 4

Regional productivity losses in a scenario of a 2ºC increase in temperature

a) Regional productivity losses **b) Regional losses and GDP per capita**



Source: Caggese et al. (2025).

Notes: Panel a) shows the productivity losses across NUTS 3 regions owing to an increase of 2ºC, which was adjusted according to the ratio of gross output to value added. Productivity losses are shown as percentages. The darker the region is shaded, the larger the loss. Panel b) plots the same regional losses against average GDP per capita in our sample, showing a negative correlation of 0.232.

Conclusions

Our paper’s findings provide two key policy insights. First, the economic impact of climate-induced productivity shocks is substantially larger when accounting for the fact that labour, material inputs and especially capital are relatively difficult to adjust. Policies that alleviate these constraints, such as promoting investment in adaptive technologies, can play a critical role in mitigating the economic costs of climate extremes. Second, our analysis emphasises the risk that climate change may make existing regional inequalities worse. The analysis highlights the need for adaptation strategies that are targeted and region-specific.

More broadly, our framework demonstrates the importance of incorporating detailed firm-level dynamics into Integrated Assessment Models to more accurately estimate the economic costs of climate change. Future modelling efforts and policy assessments must go beyond aggregated damage estimates to explicitly account for microeconomic frictions. This approach will provide a more realistic picture of economic risks related to climate change and will support the development of adaptation and mitigation policies that are more effective and targeted.

Finally, our analysis shows that firm-level responses to extreme temperatures – particularly rigidities in adjusting capital and other inputs – can significantly amplify the aggregate productivity losses from climate change. These losses have broader macroeconomic implications; reduced productivity and output can constrain supply, while climate-induced disruptions to inputs like energy and materials can fuel inflationary pressures. Understanding these microeconomic channels is crucial for anticipating the inflationary impact of climate shocks and for designing policies that enhance firms' resilience, support productive investment and safeguard economic stability in a warming world.

References

Caggese, A., Chiavari, A., Goraya, S. and Villegas-Sanchez, C. (2024), "Climate Change, Firms and Aggregate Productivity", *Centre for Economic Policy Research Discussion Paper Series,* No 19164.

Heal, G. and Park, J. (2016), "Reflections – temperature stress and the direct impact of climate change: a review of an emerging literature", *Review of Environmental Economics and Policy*, Vol. 10, No 6, pp. 347-362.

Nordhaus, W.D. (1977), "Economic growth and climate: the carbon dioxide problem", *American Economic Review*, Vol. 67, No 1, pp. 341-346.

Seppänen, O., Fisk, W.J. and Lei, Q. (2006), *Room temperature and productivity in office work*, Technical report, Helsinki University of Technology and Lawrence Berkeley National Laboratory, Helsinki and Berkeley.

Somanathan, E., Somanathan, R., Sudarshan, A. and Tewari, M. (2021), "The impact of temperature on productivity and labor supply: evidence from Indian manufacturing", *Journal of Political Economy*, Vol. 129, No 6, pp. 1797-1827.

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2.

Affected firms that are unable to reduce inputs face a 20% decline in productivity, while unaffected firms meet demand by scaling up their inputs and do not experience a loss in productivity. Aggregate productivity then falls substantially, reflecting the weighted average of productivity across affected and unaffected firms.