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THE EFFECTS OF CLIMATE CHANGE ON THE ITALIAN ECONOMY. A BANK OF ITALY RESEARCH PROJECT

by Matteo Alpino[♣], Luca Citino[♣], Guido de Blasio[♣] and Federica Zeni[♦]

Abstract

This volume summarizes the results of the research project "The Effects of Climate Change on the Italian Economy." The project consists of 17 papers that (a) measure the impact of climate change on economic activity, particularly that of the most exposed sectors (e.g., agriculture or tourism); (b) analyze some of the policies for adaptation and mitigation (e.g., simplifications of the permitting regime for investments in renewables or carbon pricing schemes).

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THE EFFECTS OF CLIMATE CHANGE ON THE ITALIAN ECONOMY. A BANK OF ITALY RESEARCH PROJECT*

Matteo Alpino, Luca Citino, Guido de Blasio and Federica Zeni

As we know, considerable changes are taking place in the planet's climate. There have been unprecedented variations in human history that will influence the conditions of life on earth for a long time: the Intergovernmental Panel on Climate Change (IPCC) reports show that while significant reductions in CO_2 emissions and other greenhouse gases would be able to limit climate change, it could take an additional 20-30 years for global temperatures to stabilize. The scientific evidence collected in the reports also supports strongly the thesis that human activities have had a discernible impact on climate over the last two centuries.

Unless large-scale emission reductions are implemented in the coming decades, it is likely that during the 21st century, the increase in the average temperature of the Earth's surface will exceed 1.5 °C or even 2 °C, depending on the emissions scenario considered. Global warming of 1.5 °C is expected to increase the number of heat waves, longer warm seasons and shorter cold seasons. If the temperature increase were 2 °C, the extremes of heat would reach critical tolerance thresholds for some human activities. In addition to global warming, climate change includes variations in possible values for humidity, wind strength, frequency and intensity of precipitation, both in coastal areas and in the oceans. In some regions, there will be more heavy rains and floods; in others, droughts. There will be a rise in sea levels, resulting in flooding and coastal erosion. The melting of permafrost, glaciers and polar ice caps will intensify. In the oceans, warming, acidification and reduction of oxygen levels will affect marine ecosystems. Although climatologists agree that, without drastic emission reductions, climate change would be substantial, there is still considerable uncertainty as to the exact extent of the damage, as well as the possibility of irreversible catastrophic events.

According to the Euro-Mediterranean Centre on Climate Change (CMCC), published in 2020, the Mediterranean area will see 20 per cent higher warming than the global average. For Italy, the various climate models agree on forecasting a temperature increase of up to 2 °C in the period 2021-2050 (compared with 1981-2010). In the most unfavourable scenarios though, the temperature rise will be much higher. A decrease in summer precipitation is expected, mainly in the central and southern regions, but this is accompanied by an increase in their intensity, while there will be a general increase in extreme climate events.

Climate change is not an irreversible process against which there are no forms of defence, but rather a complex phenomenon that links two strands of socio-economic and natural dynamics: on the one hand, the behaviour of people and businesses influences greenhouse gas emissions and thus the future evolution of the climate; on the other hand, the changes in progress affect the choices of economic agents themselves, who are trying to find strategies for mitigation and adaptation. Addressing the challenges posed by climate change requires not only an understanding of natural phenomena, but also an analysis of the functioning of

* The project was coordinated by a committee composed of Guido de Blasio (coordinator), Matteo Alpino, Luca Citino, Ivan Faiella, Luciano Lavecchia and Federica Zeni, and Cristina Petrassi and Giulia Mattei (who took care of the organizational aspects). The committee benefited greatly from the advice of Professor Valentina Bosetti (University Bocconi) and Professors Giovanni Marin (University of Urbino) and Alessandro Palma (GSSI, L'Aquila). We also thank Fabrizio Balassone, Piero Casadio and Maura Francese for their useful suggestions.

society and the economic system. In other words, the possibility of finding solutions to the problem depends on our ability to provide answers to questions of an economic and social nature, and not only those relating to physical climate Why do our economies continue to use fossil fuels so intensively, despite rapid technological progress in renewable energy? What explains the slowdown observed in innovative activity in green technologies and the acceleration in polluting technologies? Is it appropriate to start cutting emissions now or is it better to wait for access to better technologies?

For decades, economists have been developing tools and analyses to answer these and other questions. Research has helped us understand how certain behaviours of individuals and businesses that have relevance for emissions and adaptation to climate change (for example, the renovation of a building, the choice to buy an electric car or to migrate from a warm place, the exploration of new oil fields, the construction of a research laboratory, etc.) interact and combine with each other through market mechanisms, and ultimately what the repercussions for the entire economy are, through the development of aggregated variables such as GDP, price level, credit and income. Without a clear understanding of how economic agents respond to the incentives given by the market and by public interventions, climate policies could be badly designed, lose effectiveness, or even do more harm than good. For example, policies that encourage the purchase of energy-efficient goods (a state-of-the-art air conditioner) have an ambiguous effect on total energy consumption if the energy savings generated by a more efficient asset lead to it being used more — the 'rebound effect'. The actual impact of emissions policies cannot therefore be determined purely on a conjectural basis, but depends on certain parameters relating to people's behaviour: propensity to save money, desire to use a certain device, elasticity of energy demand at its price and so on. The theoretical models of economists, far from being a purely intellectual exercise, allow us to reduce a complex system to its essential components (different for each problem) and understand what quantities are important to then understand the responses of economic agents and design more effective policies.

It goes without saying that theory alone is not enough. For this reason, for more than a century, economists have based their assessments on *empirical analyses* of available data, properly conducted through statistics and econometrics. In the context of the climate change study, these analyses make it possible to accurately quantify the impact of global warming on certain sectors or markets, or the effectiveness of the adaptation strategies implemented by households and businesses, often with the support of the public sector. The real challenge of these analyses lies in the identification of cause-and-effect links, which are more important for economic policy than simple statistical correlations. Identifying such causal effects is complex because it requires the reconstruction of *counterfactual* worlds: what would have happened to energy consumption without action to improve energy efficiency? Answering such questions is difficult because data only allow you to observe the world as it is, not as it would have been. With renewed impetus since the 1990s, economists have developed rigorous and innovative methods for reconstructing these counterfactual worlds (see Angrist and Pischke, 2010). These statistical techniques, the contribution of which has recently been highlighted by the Nobel Prize in Economics awarded to Joshua Angrist, David Card and Guido Imbens, can be applied in various fields of social science, including estimating the impact of climatic variations on human activities. The results of empirical analyses based on economic theory can enable public decision-makers to put in place effective and efficient measures to counter the effects of climate change. Obviously, economists will not be able to venture alone into the study of these phenomena, but they will have to make use of the contribution of other sciences, such as climatology, geology and engineering. The advancement of our knowledge cannot ignore an interdisciplinary approach that combines the contributions of scholars from different disciplines.

The set of statistical-econometric techniques available to economists (but now increasingly used by other social scientists) can be used to evaluate the effectiveness of specific public interventions. Econometric evidence can be found in order to answer questions that have assumed particular importance in the current economic situation. For example, is a bonus for the energy efficiency of buildings desirable? How many investments would not have been made without it (again, a counterfactual world)? What is the 'right' amount for the bonus? Or, to what extent will the transport decarbonization strategy, which involves significant investments in the rail network, achieve the desired lower use of private cars for railways? These are not two randomly chosen themes, but the two main interventions for the ecological transition provided for by the National Recovery and Resilience Plan (NRRP). Being able to base economic policies on credible statistical evidence reinforces the action of the public sector, both in terms of effectiveness and transparency profiles. In the field of environmental policies, and especially with regard to our country, traditionally in difficulty with evidence-based policies (de Blasio *et al.*, 2021), economists' analyses can be valuable.

This introductory chapter aims to initiate the non-specialist reader into the issues of climate change and its effects on the economy and society. To this end, the next section explains why carbon emissions represent a global externality and what difficulties arise from this for the decarbonization process. A box describes the main institutional, international, European and Italian aspects. The next section describes how economic analysis has traditionally dealt with climate change, with an emphasis on the most recent literature using counterfactual methods. Finally, the last section summarizes the works that are part of the Bank of Italy's research project, for each of which an illustrative sheet is presented in this volume, and proposes some final considerations.

Global externality, *carbon pricing* and international coordination

The impact of greenhouse gas emissions on climate change is not dependent on their geographical origin. When a power plant burns coal — whether in China or Italy — it produces greenhouse gases that spread rapidly into the atmosphere, adding to the *global stock* of these already present gases. It must be borne in mind that climate change is caused by the concentration levels of greenhouse gases in the atmosphere, which are maintained for a very long time.[1] The significant value is therefore the *stock* of climate-changing gases, not their flow (i.e. how many emissions occur each year), although of course the flows are added to the existing stock. Taking up a famous metaphor, the climate system is like a bathtub: when it is filled with hot water, it takes time to cool it, even after turning the cold water tap on.

While the localization of emissive sources has no relevance to *global* warming, climatologists' predictions indicate that climate change will be extremely heterogeneous in different regions of the planet. Econometric analyses also indicate that the economic damage of climate change will depend on the initial conditions of each area: an increase of one degree in a temperate country has more modest consequences than the same increase in a country that is already hot.

The characteristics of climate change mean that no country taken individually has an incentive to fully take into account (*internalize* in the jargon) the costs of its greenhouse gas emissions. For example, if the Italian government decides to produce the energy that its economy needs only by burning fossil fuels, the damage of the resulting emissions would not only affect Italian citizens, but also and above all those who live in regions that are already very hot (for example the Indian subcontinent), a long way from our country. In the

[1] According to NASA, CO_2 can remain in the atmosphere for between 300 and 1000 years.

language of economists, climate change is therefore characterized by the presence of *externalities,* moreover of a *global* nature. In economics, *externalities* are defined as all the effects (positive or negative) that an economic activity or transaction has on the well-being of third parties who have not participated in it. In the case of climate change, when a power plant burns a fossil fuel to produce electricity and sell it to a consumer, someone else, perhaps in India, probably not yet born, will suffer the consequences.

From a theoretical point of view, the solution to externality problems has been known to economists since Pigou's contribution (1920): efficient public policy is to increase the cost of all greenhouse gas emissions (i.e. through the imposition of an emissions tax) so that it reflects social costs. For example, if burning gas to heat a house causes future damage, this damage should be included in the cost of gas. This approach, generally known as *carbon pricing* (literally 'attributing a price to carbon dioxide'), can be used in several ways, including the imposition of a *carbon tax* or the imposition of an emissions cap, which is associated with a market to buy or sell (*cap and trade*).[2]

Through a carbon tax, the regulator directly sets the price of emissions by defining a tax for each tonne of greenhouse gases emitted. For example, a carbon tax of €50 per tonne of greenhouse gases in the transport sector would result in a tax of about 10 cents per litre of petrol. In this specific case, the optimal tax is one that aligns the cost of fossil fuels with the externalities they cause. Extensive econometric literature has developed over the last decade with the aim of estimating the extent of externalities from greenhouse gases, what is defined in technical jargon as the social cost of carbon, and thus providing guidance on the level at which the carbon tax should be fixed. Alternatively, with estimates of the elasticity of demand for fossil fuels at their price, the level of the tax can be set in such a way as to achieve a given reduction in emissions that consistent with the containment of the global average temperature increase to 2 °C, as established by the Paris Agreement.

Through cap and trade, the regulator sets the total amount of emissions that the entire economy can produce over a given period of time and then allows companies to buy and sell emission certificates (or permits) whose total does not exceed the total amount determined. In order to determine how much each individual company has the right to issue, the regulator auctions certificates that can then also be bought and sold by individual companies. A company that intends to emit a given amount of greenhouse gases must obtain and then return to the regulator a corresponding number of certificates. Depending on the cost of abatement, each company will decide whether to comply with the regulation by purchasing more certificates or by reducing its emissions, for example by increasing its energy efficiency. Since every tonne of greenhouse gases causes the same social damage, for the regulator it does not matter how a company emits that tonne, and therefore they delegate this choice to the market. The fact that each company chooses independently whether to reduce emissions or buy permits at market price ensures that emissions are reduced at the lowest cost. Companies for which reducing emissions is more expensive than the price of a permit will choose to buy the permit and continue to issue; on the contrary, companies for which reducing emissions through alternative means — for example by increasing their energy efficiency — are lower than the price, will emit less.

Since the 2000s, the number of jurisdictions that have introduced some form of carbon pricing has increased significantly, but the spread of these schemes remains limited. In 2022, 68 such policies were active worldwide, covering just under one quarter of global emissions.[3]

[2] Although the English terms *carbon pricing* and *carbon tax* (often translated into Italian as a *carbon price or carbon tax*) refer directly to carbon dioxide, these policies cover all greenhouse gases, such as methane (CH_4) and nitrogen oxide (N_2O).

[3] See the statistics reported by the World Bank on the portal https://carbonpricingdashboard.worldbank.org/

Moreover, in many cases, the price of emissions in these systems was quite low and, in any case, lower than the negative externality associated with them.[4] Although carbon pricing is favoured by most economists,[5] its spread is hampered by political obstacles. According to recent studies, most voters are not in favour of this solution, either because they are unwilling to bear its costs in terms of higher energy prices or because they doubt that these initiatives can actually solve the problem of climate change.[6]

Moreover, the carbon pricing approach is valid if and only if you are willing to embrace a 'utilitarian' philosophy: if, in order to burn fossil fuels, individuals agree to pay an additional amount of money, at least equal to the damage done to individuals not yet born somewhere in the world, then this 'transfer of resources' from future generations to today's generations is desirable because it increases collective well-being. This approach, focused on achieving the greatest possible well-being for as many people (regardless of *who* they are), ignores the possibility that society considers certain actions unethical and therefore undesirable, no matter how much someone is willing to pay to put them in place. On the other hand, cost-benefit analysis is implicit in many of the choices our societies make. A highway will still be built even if someone might have a road accident. The debate on the appropriateness of the 'utilitarian' perspective when it comes to climate change remains open. For all these reasons, many governments use alternative environmental policies, which are essentially of two types: provision of clean energy subsidies (i.e. incentives for the installation of solar panels) and the introduction of emission standards (such as Euro VI and previous limits on emissions per kilometre travelled, which apply to cars in the European Union).

Whether it is a form of carbon pricing to internalize the cost of externality, or a combination of subsidies and emission standards, the *global* nature of the problem means that any climate policy should be applied without distinction to all greenhouse gas emitters in the world (i.e.to all coal-fired power plants) regardless of the country in which they are located. It is therefore clear that any environmental policy that aims to reduce climate change (and not pollution of a local nature) should necessarily be shared and coordinated at an international level in order to be effective. Unfortunately, it is also clear how difficult such coordination is to achieve and maintain over time. The game theory predicts that if one country unilaterally decides to cut its greenhouse gas emissions, other countries would have an incentive to keep their emissions unchanged because the costs of transitioning to a sustainable economy (that is, developing alternative energy technologies) would only be borne by the willing country, while everyone would enjoy the benefits without distinction[7] (a phenomenon known as *free riding*). Moreover, in the case of a single country's unilateral abatement, global emissions could even remain unchanged if the latter's companies decided to relocate their production to countries with a less stringent climate policy (a phenomenon known as *carbon leakage*). Finally, it is important to note that countries that today emit large amounts of greenhouse gases (typically developing countries) contribute less to current climate change than countries that currently have lower emission levels, but have consumed massive amounts of fossil fuels over the past one hundred and fifty years (typically advanced countries that were the protagonists of the first industrial revolution). Returning to the metaphor of the bathtub, the high temperature of the water already inside is the responsibility of the advanced countries, even if colder water comes out of their tap than out of that of the developing countries. This asymmetry makes it even more difficult to convince developing countries to cut emissions, as this is likely to lead to a slowdown in their process of economic convergence towards the income level of advanced countries.

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[4] The highest prices are around $130 — a figure in line with externality according to some widespread estimates (see for example Wang *et al.* (2019)) — and are recorded in Switzerland, Sweden, Liechtenstein and Uruguay.
[5] Economists' Statement on Carbon Dividends, The Wall Street Journal, January 16, 2019.
[6] See Douenne and Fabre (2022) and Dechezleprêtre *et al.* (2022).
[7] See Hoel (1991).

Historically, the coordination of climate policies at the international level has been attempted through the signing of multilateral agreements through which countries committed to certain reductions in their emissions by a certain date. Institutional developments in the international climate treaties of Kyoto (1997) and Paris (2016), and the involvement of the European Union and Italy in particular, are summarized in the box. Unfortunately, it has proved particularly difficult to enforce these treaties, as there is no international tribunal capable of punishing those who violate them; in the final analysis, each country may at any time decide to abandon an international treaty which it had previously signed.[8] A striking example is the abandonment of the Treaty of Paris by the United States announced in 2019.[9] Moreover, since the transition to a sustainable economy entails massive initial investment, every time a country takes important steps in this direction, it is simultaneously weakening its negotiating position in international fora, as its threat of reducing its commitment becomes less credible if other countries do not follow it on the road to the green transition.

Institutional developments (international and European) in the fight against climate change

The first international climate agreement was concluded in 1997 in Kyoto at the Third Conference of Signatory States (COP3) of the United Nations Framework Convention of Climate Change (UNFCCC). The Kyoto Protocol established legally binding obligations to reduce and limit greenhouse gas emissions throughout two commitment periods (from 2008 to 2012 and from 2013 to 2020 respectively) for more than 180 original signatory states. In 2016, under the UNFCCC COP21 in Paris, a second international agreement was concluded with the introduction of a quantitative target to limit terrestrial warming to less than 2 °C above the pre-industrial levels of 1750. The 196 signatory states, responsible for more than 90 per cent of global emissions, indicated their decarbonization targets for the period from 2020 to 2030.

The European Union (EU) has always played an important role in the fight against climate change. In 1997, it committed to achieving an 8 per cent reduction in greenhouse gas emissions from1990 levels between 2008 and 2012. Under the 2016 Paris Agreement, the EU committed to achieving a 40 per cent reduction in greenhouse gas emissions from 1990 levels between 2020 and 2030. In 2019, it then increased this target to 55 per cent, with a view to achieving carbon neutrality by 2050. By comparison, other high-emission jurisdictions such as China and the United States have set less ambitious reduction targets, often failing to ratify their international commitments.

The EU's main instrument for achieving decarbonization targets is the European Union Emissions Trading System (EU ETS), a cap and trade system to control polluting emissions from large electrical and industrial installations and the commercial aviation sector, representing around 40 per cent of the EU's polluting emissions. The ETS was then accompanied by sectoral measures with different objectives depending on the Member States, and investments in research and development of new technologies for carbon capture and storage (CCS).

In 2019, the EU presented the European Green Deal containing proposals for the revision and tightening of the regulation of the ETS and non-ETS sectors, as well as the imposition of ambitious targets for energy efficiency and renewable energy use.

[8] See Harstad (2012, 2016).
[9] The release, which became official at the end of 2020, followed the return to the agreements in early 2021.

In order to monitor the path towards achieving the objectives set by the Paris Agreement, EU Member States are required to send a ten-year policy document to the European Commission, providing guidance on the national macro objectives and measures necessary to achieve them (for Italy, this is the National Energy and Climate Plan (PNIEC); see below). Despite their ten-year horizon, the objectives and policy actions must be in line with the achievement of zero emissions by 2050, as already indicated in the European Green Deal.

In order to incentivize the investments needed to achieve the 2020-2030 targets, the EU has decided to allocate around one third of the NextGenerationEU budget to investments aimed at achieving the objectives outlined in the European Green Deal. These funds should also be mobilized through the issuance of green bonds by the European Commission.

The energy crisis triggered by the Russian invasion of Ukraine has imposed both temporary deviations from the decarbonization path and a strengthening of its medium- to long-term objectives.

In a context of energy emergency, Member States have intervened with a series of temporary measures to support businesses and consumers, including in some cases increasing the production of electricity from coal-fired power plants.

Last May, the European Commission presented a further plan (REPowerEU) aimed at the rapid achievement of energy independence from Russian-sourced fossil fuels, and the enhancement of renewable energy sources. The plan, integrated into NextGenerationEU, includes actions to confirm (or increase) the decarbonization objectives of the European Green Deal.

In Italy, as mentioned above, the climate objectives are indicated in the PNIEC, prepared by the Ministry of Economic Development in agreement with the Social Parties. The National Integrated Plan (NIP) covers the following topics: (1) energy efficiency and renewable sources (2) emissions reduction (3) internal markets and interconnections and (4) research and innovation.

The most recent NIP, approved at the end of 2019, envisages a 40 per cent reduction in greenhouse gas emissions compared with 1990, in line with the European targets set under the Paris Agreement, and will require an update to be in line with the new European target of 55 per cent. The main objectives of the NIP are: (I) a substantial reduction in greenhouse gas emissions compared to 2005 (-43 per cent in installations bound by ETS and -33 per cent in the remaining sectors); (II) an increase in the share of renewable energy (30 per cent of total gross energy consumption and 22 per cent of transport consumption); (III) a 43 per cent reduction in primary energy consumption compared with the PRIMES 2007 scenario.

In Italy's Recovery and Resilience Plan, defined as part of NextGenerationEU, the investments of the 'Green Revolution and Ecological Transition' mission amount to almost €70 billion.

Economic theory has proposed various mechanisms to alleviate the problem of free riding and to facilitate international cooperation in climate treaties, analyzing various factors such as voting rules, duration, size and negotiation procedures. Despite these attempts, several economists, including the 2018 Nobel Prize winner for Economics William Nordhaus, doubt that an international agreement can be durable, shared and sufficiently stringent to lead to significant emission reductions. Nordhaus promoted an alternative approach to the problem: a small number of virtuous countries, eager to stop climate change (a *climate club*), should unilaterally implement an aggressive climate policy (for example, by introducing an ambitious carbon tax) and, at the same time, should impose trade duties on imports from countries that are not members of the club.[10] The tariffs could be proportionate to the amount of greenhouse gases used to produce imported goods to partially extend the club's climate policy outside its jurisdiction as well. Alternatively, the customs duties could be uniform in order to function as a punishment for not being part of the club.[11] In any case, Nordhaus's proposal only has some chance of success if the initial size of the club in terms of foreign trade is large enough to make the threat of a trade war an effective deterrent.

The effects of climate change on the economy and society

What is the impact of climate change on the economy? Since the 1970s, economists have been trying to answer this question through Integrated Assesment Models (IAMs), which form the basis for important economic policy requirements, such as the level of a carbon tax. These are macroeconomic models integrated with climatological models, which provide a quantitative description of the processes in place in both the social and natural systems, taking into account the interactions between them. These models allow us to make forecasts for future developments in climate-changing gas emissions depending on changes in the structure of the economy and economic policy interventions. They also allow us to make estimates of the economic damage caused by climate change, taking advantage of climatological information on the relationship between emissions and climate and between climate and GDP (damage function). Like any quantitative model, IAMs are based on assumptions about the functioning of the economy that serve to reduce a highly complex system to a set of relationships and causal links between a few variables.

IAMs models have been widely criticized (Stern and Stiglitz, 2021). Regarding the estimation of the economic costs of climate change (damage function) Pindyck (2013) argued that, given the arbitrariness of some crucial assumptions, the quantification of the damage resulting from these models would reflect nothing more than conjectures. However, the progress in recent years has been significant in this respect. The availability of data and that of a greater and widespread computing power, together with the development of counterfactual statistical techniques, has enabled considerable progress in the study of the (positive or negative) effects of climate on socio-economic variables. The estimation of past effects can then be used to simulate the impact of future climatic variations, so as to replace the elements of arbitrary damage function with estimated elasticities on the data. This reading is well summarized in Dell *et al*. (2014), Carleton & Hsiang (2016), and Hsiang & Kopp (2018). It is mainly in this line of research that the works included in the Bank of Italy's research project, which uses counterfactual microeconometric techniques to assess the effects of climate change that have already been experienced in certain sectors and markets in our country.

As mentioned above, identifying the causal effect of a given climate change on a socio-economic variable requires *counterfactual* reasoning. Let's imagine that in a week of extremely high temperatures, 52 elderly people have been admitted to hospital in Foggia. Can we say that the heat caused those admissions? The answer is no. A certain share of elderly people would probably have been admitted to hospital even at much more acceptable temperatures. The ideal experiment to allow us to accurately measure the effect of the climate needs a comparison. We should consider two populations of elderly people, absolutely identical in each characteristic, including that of living in Foggia, one that

[10] See Nordhaus (2015).

[11] The latter approach is easier to implement in practice, given the high administrative burden that would be required to calculate the amount of greenhouse gases emitted for the production of each imported commodity.

experiences the week with very hot temperatures (the treatment group) and the other that does not (the control group). In this way, the difference in hospitalization rates can be reasonably attributed to the climate. In fact, this experiment is not achievable, since older people can find themselves in only one of the two states depending on the real temperatures they experience in that week.

Econometrics provides the methods to approximate the ideal experiment that cannot be achieved. The first attempts exploited climate variability in the territory (Mendelsohn *et al.*, 1994): since the elderly people of Foggia cannot be used for the control group, why not use those of Trento, who experienced very mild weather during that same week? This path (cross-sectional comparisons) has limitations. The elderly in Trento differ from those of Foggia for a variety of factors (income and wealth, functioning of local public services, cultural background, eating habits, etc.) that could play a role in the different hospitalization rates for that week. However, these important limitations are accompanied by a clear advantage: cross-sectional exposure to the climatic conditions of the treatment and control groups has a long duration, so it is plausible to assume that the response of the agents takes into account the adaptation activities that individuals have put in place to defend themselves against climatic conditions (e.g. the elderly in Foggia suffering the most uncomfortable temperatures have equipped themselves with air conditioners).

A different path is the one that exploits the variability of the climate over time. In practice, it is used as a control group for the counterfactual comparison for the same treated population, that of Foggia, but taken at a different time from that of the week in which extreme temperatures were experienced (longitudinal comparison or panel). In this way we take into account the fact that some of the factors that can explain the differences in hospitalization rates over time do not vary and therefore do not confuse the effect of the climate on the variable we have taken as a reference. Again, the interpretation of the results of counterfactual estimates requires caution. The main difficulty is that they represent short-term responses, which do not take into account adaptation activity. The most recent methodological developments (see for example Kolstand & Moore, 2020) propose hybrid approaches, in which sources of cross-sectional and temporal variability (even over very long periods) are combined to obtain estimates that are reasonably safe from the problems of omitted variables and that at the same time can take into account responses in terms of adaptation.

The applications of these techniques show that climate change has important repercussions on the economy and society. First, there are significant effects on aggregate measures of economic activity, such as GDP or national income. For example, Burke *et al.* (2015) show that on a global scale, the estimated relationship between the change in GDP per capita and the average annual temperature would be peaking at an annual average temperature of 13 °C and then quickly decrease beyond this threshold. Using these estimates, according to the CPR 8.5 scenario,[12] the decline in global GDP per capita at the end of the century could be just under a quarter of that of a counterfactual world without climate change (this change corresponds to a reduction in the average growth rate of 0.28 percentage points from 2010 to 2100). In an exercise limited to the United States for the period 1969-2011, Deryugina and Hsiang (2017) estimate that the temperatures actually experienced by the different American counties would have reduced the rate of growth by 1.7 percentage points with respect to what would have been achieved if the temperature had always been the optimal one for the performance of production activities (between 9 °C and 15 °C). According to

[12] CPR (Representative Concentration Pathways) are emissions scenarios used in global climate models. CPR 8.5, the most extreme scenario currently considered by the IPCC, foresees an overall increase in emissions compared with 2005 to around 1,000 gigatonnes of CO_2 equivalent by 2030 and around 2,500 gigatonnes by 2050 (Schwalm *et al.*, 2020; Bernardini *et al.*, 2021).

these estimates, the annual growth rate of the U.S. economy would, in the case of SPR 8.5, be lower by a value in the range of 0.06 to 0.16 percentage points compared with a counterfactual without climate change. The effects of climate change in macro studies appear to be fairly homogeneous across areas of the world and across different eras, once the initial climatic conditions have been taken into account. In other words, the effects would be more pronounced in poor subtropical countries due to their climate and not to their economic starting conditions.

Under what mechanisms does the climate impact aggregate economic activity measures? Economic analyses immediately focused on agriculture, given the role of climatic conditions for harvests. Some of the important methodological developments mentioned above and which allow us to accurately measure the effects of climate on socio-economic variables derive from applications in the agricultural sector. For example, Mendelsohn *et al*. (1994), using a cross-sectional approach, estimate that the effect of climate on land values is very modest. Schlenker *et al*. (2005) show that the possibility of artificial irrigation, which Mendelsohn *et al.*'s work *(*1994) does not consider, represents a crucial omitted variable, the inclusion of which involves a substantial upward revision of the damage. Turning to the approach that exploits climate variability over time of temperatures and precipitations (less sensitive to distortions due to omitted variables), Deschênes & Greenstone (2007) do not find significant effects. On the other hand, these findings have been criticized and refuted in a series of subsequent studies, indicating instead that climate change has negative and significant effects on various crops (Fisher *et al.* 2012). Adaptation remains a highly debated aspect: it could be limited by a lack of awareness of farmers or insufficient access to credit.[13]

The effects of climate on aggregate economic activity could hardly be explained by reference to agriculture alone, which in richer countries occupies a small fraction of the product. Many recent contributions look at the implications for productivity in sectors other than the primary one. For example, Somanathan *et al*. (2021) use enterprise-level data relating to the Indian manufacturing sector to show that on hot days, labour productivity decreases and absence from work increases. One result of the study is that, while the former could be protected from adverse climatic conditions through air-conditioning systems at the workplace, the latter does not depend on the existence of air conditioners in the plants, suggesting that, to limit the damage, the adaptation measures must also concern housing and means of transport. On these issues, and on the mechanisms of transmission of environmental conditions to individual work performance, see, among others, Heal & Park (2016) and Graff Zivin & Neidell (2014).

The studies have focused not only on purely economic variables, but also on equally important ones, to which it is difficult to attribute a monetary value, such as biodiversity and mortality. On the latter, a recent study (Carleton *et al*. 2022) analyzed provincial age mortality data covering 55 per cent of the planet's population. The results indicate a substantial heterogeneity, depending on the initial conditions: in an extreme scenario, global warming would save about 230 lives a year per 100,000 inhabitants in Norway, and cause 160 more deaths in Ghana. The difference is due to the different climatic and economic starting conditions of the two countries. Although higher temperatures can cause significant loss of life, the study also reveals that adapting and improving living standards in developing countries should be able to strongly mitigate these negative effects.

More generally, studies have covered a variety of fields, many of which are of interest to economists. Important examples relate to the accumulation of human capital (see for

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[13] Recently, economists have finally begun to investigate 'CO^2 fertilization', i.e. the phenomenon that this greenhouse gas has a fertilizing effect on some crops; a recent study (Schlenker and Taylor, 2021) indicates that the increase in CO^2 in the atmosphere is responsible for at least 10 per cent of the increase in agricultural productivity observed in the United States since 1940.

example: Park *et al*., 2020), migration (Cattaneo & Peri, 2016), demography (Barreca *et al.*, 2015) and crime (Baysan *et al.*, 2018). These are important issues for the Italian case; it is easy to imagine that the implications of climate change in these areas will soon be at the centre of the policy debate.

The Bank of Italy's research project

The works of the Bank's research project contribute both to estimating the effects of climate change on the Italian economy and to evaluating certain policies. With regard to the effects of climate change, as already mentioned, agriculture is one of the most exposed sectors, as temperatures and precipitation are direct inputs into the production process. In one of the works of the project (Accetturo and Alpino, 2022), an econometric analysis of corn, durum wheat and wine grapes reveals that in the Italian case, the negative effects on the yield of these crops occur when the temperature rises above about 29 °C for cereals and above 32 °C in the case of vines. Agriculture is also exposed to extreme events such as hailstorms, but few Italian farmers are insured against this type of risk, despite the existence of state subsidies. Citino, Palma and Paradisi (2021) show that this under-insurance is attributable both to the phenomenon of adverse selection — so that the prices observed are convenient only for the producers most at risk — and to 'frictions' on the demand side, i.e. a set of psychological and cultural factors that lead farmers to underestimate the value of insurance contracts. Buttons, Fridge and Garnet (2022) show that EU funds under the Common Agricultural Policy (CAP) have a positive effect on the likelihood of securing and also increasing investments in crop protection.

As found in international literature, even in Italy, agriculture is not the only economic activity to be affected by the effects of climate change and related events. Cascarano, Natoli and Petrella (2022) show evidence, covering all sectors, that the increase in the number of days of high temperatures reduces the market entry rate of new companies and increases the exit rate; another contribution (Clò, David and Segoni, 2022) shows that negative effects on the demographics and performance of enterprises in all sectors are also caused by hydrogeological events (especially floods), the frequency of which is increasing due to climate change. Mariani and Scalise (2022) focus on the effects of decreasing snowfall on winter tourism, and conclude that this phenomenon has negative and significant effects on tourist flows. The real estate market also appears to be conditioned by high temperatures, with effects relating to the fact that the heat discourages buyers from looking for houses (Cascarano and Natoli, 2022). The negative impact of climate change on economic activities is so pervasive that it can also be grasped by using aggregate macroeconomic variables, as demonstrated in Brunetti, Croce, Gomellini and Piselli (2022), who use historical series on temperatures and gross domestic product for a period of time from the end of the nineteenth century to the present day.

The negative effects of climate change affect not only the productivity of economic activities but also that of individuals. Ballatore, Palma and Vuri (2022) relate the *performance* of Italian students in the Invalsi tests with the temperatures recorded on the day of the test; empirical analysis reveals that more than 30 °C have negative effects both on test results, especially in mathematics, and on students' emotional stress levels. According to the medical literature, air pollution can also have negative effects on human performance, because it alters concentration and mental readiness; in line with this mechanism, another work (Depalo and Palma 2022) shows that poor air quality causes more accidents at work, especially in outdoor activities.

The research project also includes four contributions aimed at assessing the effectiveness of certain environmental policies. Dal Savio, Locatelli, Marin and Palma (2022) analyse a reform of the European Union's cap and trade system (known as the Emission Trading Scheme or ETS) which has reduced the amount of issuance permits available free of charge since 2013; the results show that this tightening of regulations had no adverse effects on productivity or on access to international markets of the companies involved. Daniele, Pasquini, Clò and Maltese (2022) focus on some measures to simplify the authorization procedures necessary to build photovoltaic plants introduced by the Regions, and conclude that they are effective in increasing installed capacity. Caprioli and Caracciolo (2022) use a macroeconomic model to study the distributive effects of the introduction of a carbon tax in Italy, showing that the negative effects on household incomes, which are more pronounced for the poorer ones, can be offset by appropriate redistributive measures. Finally, Messina and Tomasi (2022) compare an innovative waste taxation method based on the actual production of waste with the waste tax (TARI), which is instead calculated on the basis of the area of the dwelling and the number of household members. The results show that municipalities that adopt the first method produce less waste, especially unsorted waste, with consequent savings both in terms of costs and environmental impact.

Another strand of the project analyses the behaviour of Italian companies struggling with the ecological transition process. In Italy, innovative green activity, as can be seen from the analysis of patents filed, has been decreasing since 2008, to a greater extent than in other European countries (De Luca, Greco and Lotti, 2022). Narrowing the focus to the automotive sector, another paper (Orame and Pianeselli, 2022) shows that, since 2015, Italian companies have prioritized patent activity at the expense of mergers & acquisitions in order to acquire the skills necessary to face the transition to the electric car, but still lag behind French and German competitors. Finally, Accetturo, Barboni, Cascarano, Garcia-Appendini and Tomasi (2022) highlight a link between financing and ecological transition, showing that a greater supply of bank credit increases the propensity of companies to invest in green technologies to a greater extent than in ordinary technologies.

Conclusions

The research project, whose work is summarized in this volume, is a first step in the analysis work on climate change issues that will be carried out at the Bank of Italy in the coming years. In this first phase, we focused primarily, although not exclusively, on the physical risks to the real sector and the examination of some intervention options, but many other equally important areas of research have remained unexplored. Relevant topics to which our focus is now shifting include the effects of the green transition on price dynamics, on the distribution of workers between sectors and occupations, on the financing relationships between companies and banks, and on the conduct of monetary policy.

The importance of research on these issues, and in particular on the costs and benefits of the green transition, has increased in light of the energy crisis that began in 2021 and has continued with the invasion of Ukraine. The need to achieve energy independence from Russia, enshrined in the European Commission's RePowerEU plan, means accelerating the green transition, in particular by increasing installed capacity from renewable sources. It is important that the measures that Europe and national governments have put in place to reduce the impact of the energy crisis on the budgets of households and businesses (e.g. those with a renewed use of fossil fuels or weakening price signals) do not hinder the achievement of longer-term decarbonization targets. This is an exceptionally complicated challenge. We believe that a contribution can be made by rigorous empirical analyses that can help formulate effective policies.

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1. THE IMPACT OF CLIMATE CHANGE ON ITALIAN AGRICULTURE BY 2030

Antonio Accetturo* and Matteo Alpino*

Classification of JEL: Q10, Q54

Keywords: temperature shock, precipitation, agricultural yields, climate change.

Introduction. Agriculture is the sector most exposed to the physical risk posed by climate change because temperature and precipitation are inputs in the crop production function (Deschênes and Greenstone, 2007). Net of adaptation activities,[1] the signs and the extent of this risk vary between crops and regions of the world, depending on the sensitivity of agricultural products to meteorological changes and on the initial climatic conditions (Schlenker and Roberts, 2009).

As in many advanced economies, the incidence of the agricultural sector in Italy is rather limited. The value added generated by the primary sector accounts for approximately 2 per cent of the total. However, Italian agriculture plays a significant role as a supplier of intermediate inputs to other relevant sectors for the national economy, such as the agro-industry and the tourism sector. Moreover, Italian agricultural products account for an important share (over 80 per cent) of the final consumption of primary goods by households. This implies that fluctuations in the quality, quantity and prices of agricultural products have a direct impact on the welfare of final consumers.

There is a great deal of economic literature aimed at estimating the effects of climate change on agriculture by linking weather variables and agricultural outputs (e.g. productivity, yields, profits, land prices), especially on US data. The most recent studies suggest that the effects will be negative overall, although null or even positive effects cannot be ruled out in the short term and/or in the most optimistic future scenarios. The uncertainty around these estimates is high and this partly depends on the climate model used. A recent study on Italian data (Bozzola *et al.,* 2018) suggests that the land value of irrigated farms will decrease by between 8 and 25 per cent in the period 2031-2060 compared with 1971-2000 in the RCP 4.5 scenario (characterized by moderate greenhouse gas emissions),[2] while non-irrigated farms will experience an increase in land value of between 0 and 20 per cent.

In our contribution (Accetturo and Alpino, 2022), we estimate the impact of climate change on the agricultural yields of corn, durum wheat and grapevines, which are among the main Italian agricultural products.[3] Corn production in Italy is concentrated in the North (Figure 1.1), especially in the Po Valley, where summer temperatures are relatively high and water (in terms of precipitation and availability for irrigation) is more abundant. Durum wheat – which requires warm conditions and less water – is concentrated in Southern Italy. Grapevines can grow in very heterogeneous conditions, but generally require cool springs and mild summers; water requirements can also be very variable depending on the type of grapes. For these reasons, grapevines can be cultivated almost everywhere in Italy.

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* Bank of Italy.

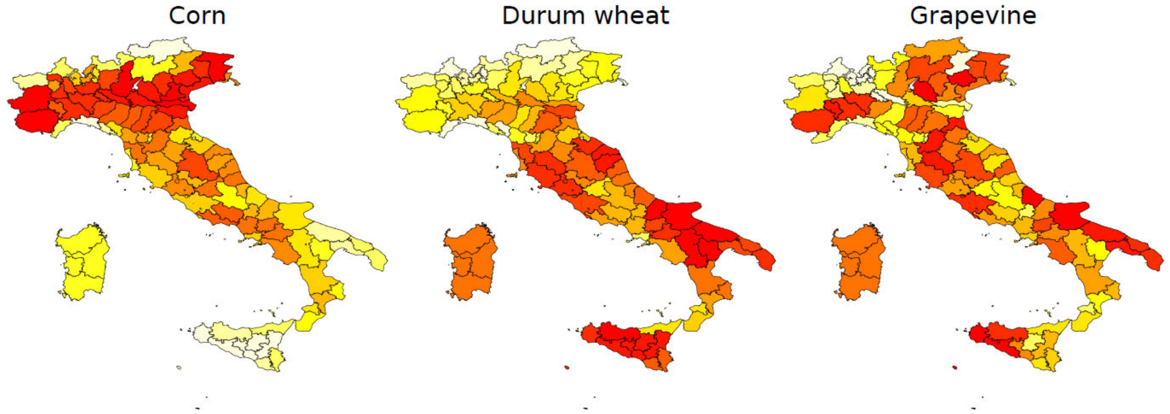
[1] Adaptation refers to the set of actions aimed at adapting an activity to a new climate. As far as agriculture is concerned, some examples include switching to new crops or crop varieties, using new technologies (e.g. irrigation) or changing the altitude of cultivated fields. Because of its varied nature, it is not easy to quantify adaptation and its effects.

[2] See footnote 17 in the introduction.

[3] The work focuses on these three crops because of their heterogeneity in terms of plant growth conditions and geographical areas of cultivation.

Figure 1.1 Provincial distribution of crops

(farmed land; 2006-2019 average)



Note: Sixteen quantiles. Darker colours correspond to a larger farmed surface in absolute terms.

Source: Own calculations using ISTAT data.

The right amount of heat and rain. — In our work, we use a well-established two-stage empirical approach. In the first, we estimate the sensitivity of agricultural yields to temperature and precipitation; in the second, we project the effects of climate change in 2030 using the parameters estimated in the previous stage together with future climate forecasts made by the Joint Research Centre (JRC) of the European Commission.

In the first stage, we use annual Istat data on total production and cultivated areas by province for the period 2006-2019. We calculate crop yield as the ratio of total production to cultivated land. We estimate the relationship between yields and weather conditions using data from the JRC Agri4cast MARS Meteorological Database, which contains daily information on minimum and maximum temperatures and precipitation.

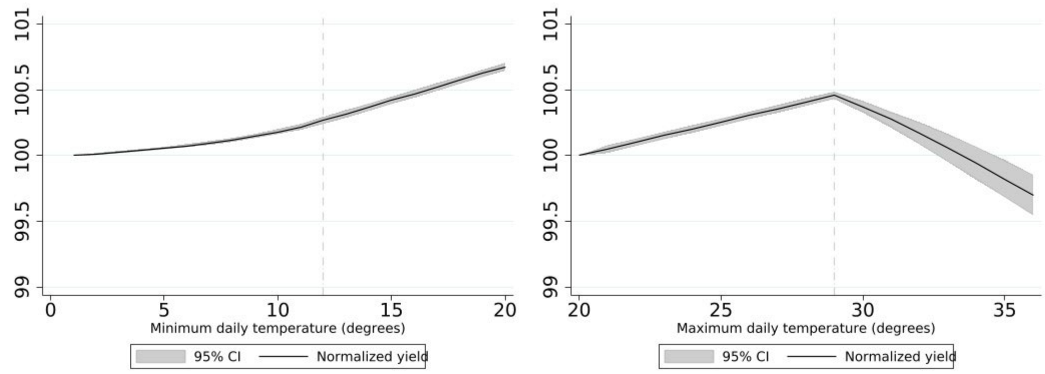
The relationship between temperature and agricultural yield is typically nonlinear; for example, a one-degree Celsius increase can have positive effects on crops if the temperature is at 20°C, but negative ones if it is at 30°C. For this reason, our analysis relies on degree-days (rather than average daily temperatures), which allow us to measure how long the plant remains exposed to different temperature ranges in each day. In the intermediate range, the temperature is growth-friendly; if is too hot or too cold, the plant is damaged with negative effects on yields. We select the boundaries of these ranges using a data-driven approach.

The relationship between yield and precipitation is also nonlinear. The impact of rain is generally positive up to a certain threshold, and then becomes null or negative when rainfall is excessive. Irrigation can mitigate the problems caused by lack of rainfall, especially in areas endowed with aquifers, rivers, lakes or aqueducts.

Too hot is bad for crops. — Our results show that average maximum temperatures above 28 °-29 °C damage the yields of corn and durum wheat. Grapevines instead are relatively insensitive to temperature changes: the negative effect appears at over 32 °C and it is less marked. The impact of precipitation is more limited, positive for corn and zero for the other crops.

More in detail, the relationship between minimum temperatures and corn yields is positive and becomes steeper above 12°C (Figure 1.2): a rise in the minimum temperature has a positive effect on yields due to increased exposure to temperatures between 12° and 29°C. The relationship between maximum temperatures and yields is not monotonous: the slope is positive below 29°C and becomes negative beyond that point; the negative part is particularly steep, suggesting that higher temperatures quickly become very harmful.

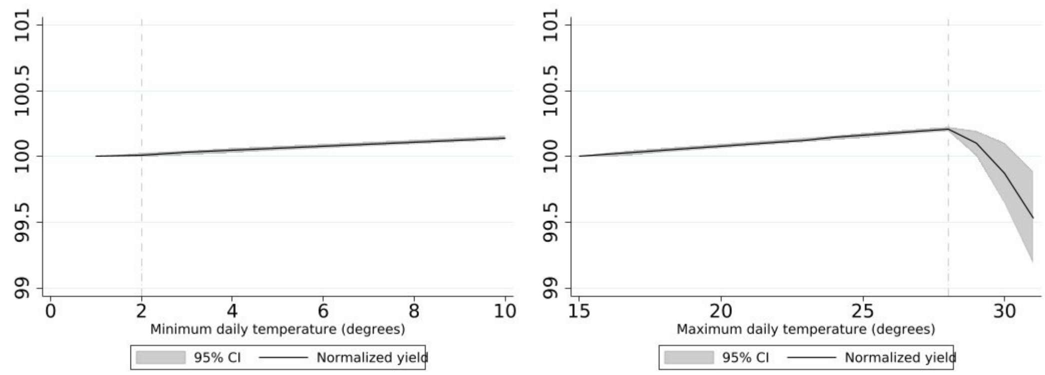
Figure 1.2 Estimated relationship between corn yields and temperatures



Note: In the left-hand panel, the yield is normalized to 100 when the minimum temperature is 1°C, and the maximum temperature is set at 22°C. In the right-hand panel, the yield is normalized to 100 when the maximum temperature is 20°C, and the minimum temperature is set at 16°C.

The effect of temperatures on durum wheat is qualitatively similar to that on corn. The relationship between minimum temperature and yield is positive and linear, although with a lower slope (Figure 1.3); the relationship between maximum temperatures and yields is positive below 28°C and negative beyond that threshold. Again, the effect of a further rise in the maximum temperature beyond this point is particularly detrimental.

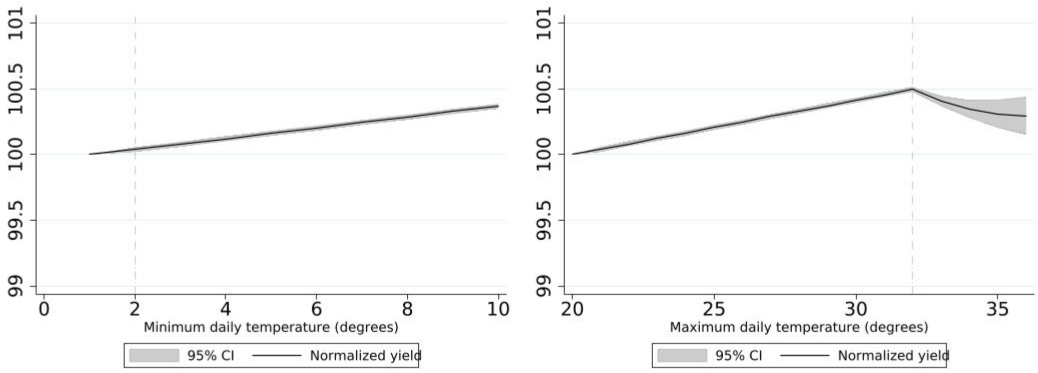
Figure 1.3 Estimated relationship between durum wheat yields and temperatures



Note: In the left-hand panel, the yield is normalized to 100 when the minimum temperature is 1°C, and the maximum temperature is set at 14°C. In the right-hand panel, the yield is normalized to 100 when the maximum temperature is 15°C, and the minimum temperature is set at 12°C.

An increase in the maximum temperature causes more moderate damage to grapevines than to the other two crops (Figure 1.4): the relationship with the maximum temperature is positive up to 32 °C and becomes only slightly negative beyond that threshold. When modifying the estimation model so that the effect is allowed to vary between the sub-periods 2006-12 and 2013-19, the results suggest that such low sensitivity to heat only appears in the second sub-period. This could indicate that Italian winegrowers are investing in adapting their production to climate change, although our short time series suggest caution in this interpretation.

Figure 1.4 Estimated relationship between wine grape yields and temperatures



Note: In the left panel, the yield is normalized to 100 when the minimum temperature is 1°C, and the maximum temperature is set at 14°C. In the right-hand panel, the yield is normalized to 100 when the maximum temperature is 20°C, and the minimum temperature is set at 15°C.

What to expect in the next decade — The results obtained so far can be used to estimate the impact of climate change on future agricultural productivity. To this end, we take advantage of the climate projections developed by researchers at the Joint Research Centre (JRC) of the European Commission (Duveiller *et al*., 2017), who make forecasts on climate in 2030 at a very disaggregated geographical level. To obtain these climate projections, scientists use complex climate models capable of simulating the evolution of weather variables in a given scenario, characterized by assumptions on the future evolution of greenhouse gas emissions. The JRC provides projections from three different climate models in the A1B scenario, which assumes very rapid global economic growth, low population growth and a balanced use between fossil and renewable energy sources.[4] In this scenario, these models predict that maximum temperatures would increase less in Italy than in Spain or France; the rise would be lower than 1°C in two models and lower than 1.4°C in the third one.

Combining our estimates with the JRC projections, the change in corn yields over the period 2000-2030 would be between -0.8 and 6 per cent. For the two climate models with less warming, the effect is positive; in the less optimistic climate model, the impact becomes slightly negative. At local level, the effects of rising temperatures display a certain heterogeneity across provinces (Figure 1.5). Using the forecasts of the two most optimistic models (side panels) the impact in the Northern provinces (and, in particular, in the Po Valley) — where production is concentrated — is positive; using the other model (central panel), the effect is negative.

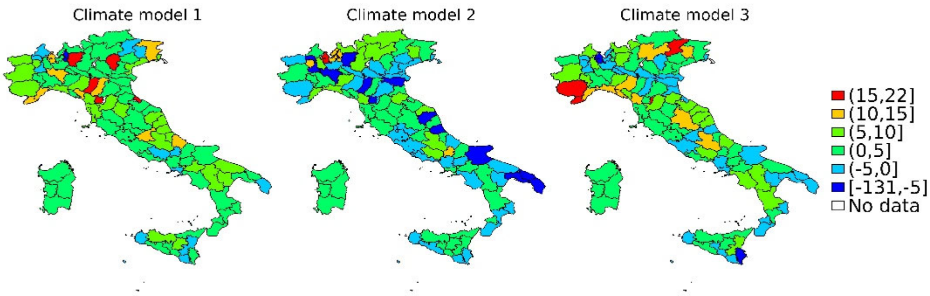
Regarding durum wheat, projections for 2030 indicate a possible increase in yields. The change in yields is projected to be between 2.5 and 5 per cent; the effect is greater when using projections of the climate model characterized by the higher increase in temperatures. Projections at provincial level indicate a negative effect in the North and a largely positive impact in the South, where durum wheat production is concentrated (Figure 1.6).

The impact of the rise in temperatures on grapevines is even more positive. Different models provide similar results: yields would increase on average by 11 per cent. Again at local level, effect heterogeneity is limited (Figure 1.7): only a few provinces would record a decrease or a sharp increase, and the latter case is concentrated in the North.

[4] The A1B scenario is part of the Special Report on Emissions Scenarios (SRES) that are no longer in use. For more information on scenarios, see footnote 17 in the introduction.

Figure 1.5 Projected effect on corn yields

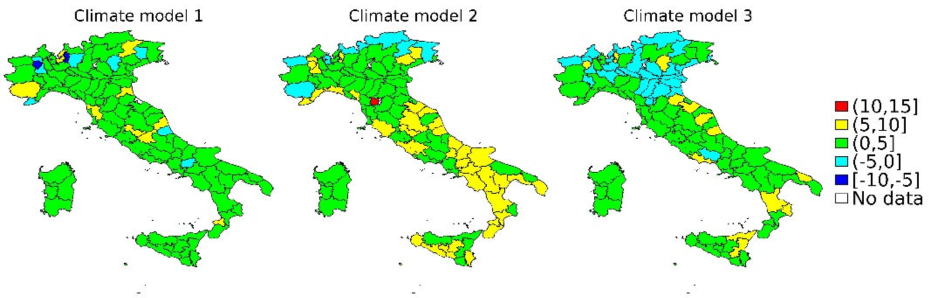
(2000 vs 2030 percentage changes)



Note: Numbers 1, 2 and 3 refer to climate models DMI-HIRHAM5-CHAM5, ETHZ-CLM-HadCM3Q0 and METO-HCHadRM3Q0-HadCM3Q0 respectively.

Figure 1.6 Projected effect on durum wheat yields

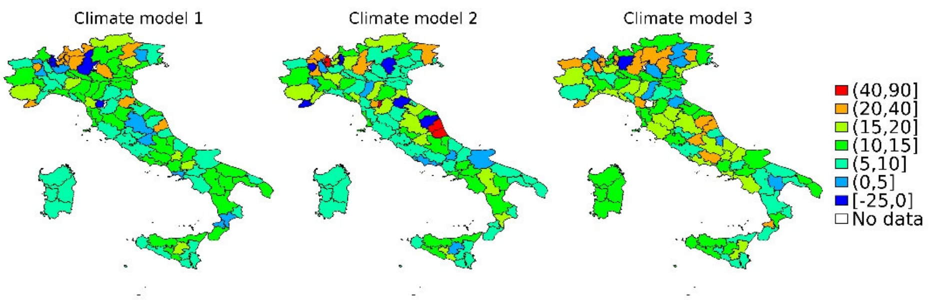
(2000 vs 2030 percentage changes)



Note: Numbers 1, 2 and 3 refer to climate models DMI-HIRHAM5-CHAM5, ETHZ-CLM-HadCM3Q0 and METO-HCHadRM3Q0-HadCM3Q0 respectively.

Figure 1.7 Projected effect on grapevine yields

(2000 vs 2030 percentage changes)



Note: Numbers 1, 2 and 3 refer to climate models DMI-HIRHAM5-CHAM5, ETHZ-CLM-HadCM3Q0 and METO-HCHadRM3Q0-HadCM3Q0 respectively.

Beyond 2030: some cautionary notes — Our projections, based on a moderately optimistic scenario in which temperatures increase moderately by 2030, suggest the possibility of positive or null effects on agricultural productivity. However, it is likely that temperatures will increase more over longer time horizons and/or in more pessimistic scenarios than A1B ones (see climate projections in Spano *et al.*, 2020). In these cases, daily temperatures will more frequently exceed the tolerance threshold beyond which greater heat becomes harmful to the crop and, as a consequence, yields will decrease (see the right-hand panels of Figures 1.2, 1.3 and 1.4). Moreover, climate change could generate not only an increase in average maximum temperatures, but also an increase in the frequency and duration of heat waves which, as shown in a very recent study (Miller *et al., 2021*), could have a significantly negative impact on crops.

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2. THE SUBSIDIZED AGRICULTURAL INSURANCE MARKET: AN EMPIRICAL ANALYSIS

Luca Citino♠, Alessandro Palma♦ and Matteo Paradisi♣

Classification of JEL: Q54, G22

Keywords: subsidized insurance, subsidies, adverse selection.

Introduction. During the COP-26 in Glasgow, Petteri Taalas, the Secretary-General of the World Meteorological Association, declared that extreme weather events will become the 'new norm'. Indeed, these climate events have increased considerably in frequency and intensity in recent decades; a trend that will probably continue in the years to come (Seneviratne, 2012).

Agriculture is among the economic sectors most affected by extreme events, because a stable and predictable climate is a crucial input for crops. Heavy hailstorms, droughts, floods, rain and strong wind can damage the crops and structures of farms, reducing their productivity in the long term (Chau *et al.*, 2019).

Despite potential losses and substantial state subsidies, farmers' propensity to protect themselves with insurance contracts remains low, albeit strongly heterogeneous across areas, in many European countries (Bielza Diaz Caneja *et al.*, 2008; Ramsey and Santeramo, 2017). In our research work (Citino *et al.*, 2021) we analyse the reasons that explain the lack of dissemination of this tool and discuss, in light of our findings and of the scientific literature on the subject, which public policies could be useful to encourage greater insurance coverage.

There are two possible inefficiencies in insurance markets. — Economic theory identifies two possible explanations for low insurance coverage: the first is related to the malfunctioning of insurance markets in the presence of information asymmetries[1] between farmers and insurers. When insurers fail to perfectly observe the riskiness of individual agricultural firms, they will only be able to charge a premium that reflects a 'medium' risk. At this price, only the riskiest individuals will want to buy insurance; on the contrary, the least risky will not because the price is too high. Information asymmetries lead to *adverse selection* among farmers, who take advantage of greater awareness of their riskiness to their own benefit. If there are buyers that are riskier than initially expected, insurers will have to raise premiums to reflect the new 'medium' risk. This would lead to further exit of less risky farmers, leading to a vicious circle of lower insurance coverage and higher prices than would be socially efficient (Einav *et al.*, 2010).

In the agricultural insurance market, the presence of information asymmetries is a concrete possibility: although climate risk information is common knowledge in principle, individual farmers' ability to defend themselves against the effects of extreme events can constitute private information. Furthermore, insurers may find it too expensive to collect a large amount of information about agricultural firms in order to charge a price that reflects individual risk more faithfully.

♠ Bank of Italy.
♦ GSSI and CEIS Tor Vergata.
♣ EIEF.

[1] An information asymmetry is a condition that occurs when one of the two counterparties in an exchange has less information than the other. This lack of information usually concerns the important characteristics of the counterparty.

If information asymmetry cannot be eliminated, the literature suggests two ways to limit its effects: subsidize demand until the amount one would get in a market without informational asymmetries is reached, or oblige everyone to buy insurance. While the first solution brings the least risky individuals back into the market, the second eliminates the possibility for those same individuals to leave the market when the price rises too much. Understanding which is the best choice depends on the context and cannot omit a precise quantification of the elements at stake. Subsidies involve a cost to the public finances, while mandating insurance imposes an excessive cost on the least risky agents.[2]

The second economic explanation for the low coverage, recently advanced in the public debate as well, is that farmers lack a real insurance culture (Ismea, 2018), so they would not recognize the potential value of this instrument, and therefore insure less than they should. Although it is difficult to separate factors of cultural and psychological origin, recent international studies have provided evidence of low insurance coverage (for other, non-agricultural risks) due to rational inattention (Chang *et al.,* 2018),[3] inertia (Handel, 2013) and underestimation of risks (Barseghyan *et al.*, 2013). Such 'frictions' (as they are called in the literature) constitute an inefficiency, as they prevent economic agents from recognizing and making choices that would be in their interest.

Solving the problem of frictions on the demand side in markets with adverse selection is not easy. For example, if it is true that information campaigns that promote greater awareness of the risks among farmers may increase their ability to make good choices, such campaigns could at the same time increase the degree of adverse selection. The reason is simple: the more farmers make informed choices, the more likely they are to use information about their risk to their own benefit.

Another thing to note is that in the presence of frictions, subsidies become more expensive, as more money is needed to get farmers to insure. This mechanism can increase the preferability of mandating insurance. As always, the choice between the two instruments requires a precise quantification of the quantities at stake and cannot be established a priori.

An important lesson emerges: given that the possible responses of economic policy depend primarily on the type of inefficiency; it is important to understand the exact nature of the problem. In the following, we provide a brief description of the empirical strategies we have adopted to detect the possible presence of these two inefficiencies in the Italian market.

Using data to discriminate between adverse selection and 'demand-side frictions'. — We have tried to use statistical tests that discriminate between the adverse selection hypothesis and that of demand-side frictions. For this purpose, we have used the SicurAgro database, provided by the Institute of Services for the Agricultural Market (Ismea). For each type of cultivation in each municipality, the database provides detailed information on the number of contracts signed, the total values insured, the premiums paid and the values compensated. To measure climate risks, we crossed these data with information from the European Severe Weather Database (ESWD), which provides geolocalized information on the history of extreme weather events.

In case of adverse selection, those who are willing to pay more for an insurance contract are on average riskier (and therefore more expensive to insure). One way of testing the presence of this phenomenon is therefore to check whether the riskiness (measured as euro compensated per insured euro) is greater among those who have paid the most for a given

[2] Mandatory insurance is the path followed, for example, by the National Health System or by unemployment benefits (both forms of insurance), to which we all contribute through taxes, without the possibility of not paying them.

[3] Rational inattention is the idea that economic agents cannot pay attention to every possible contingency, and therefore only focus their resources in terms of attention on the most important elements: those where their action can have greater consequences for their well-being.

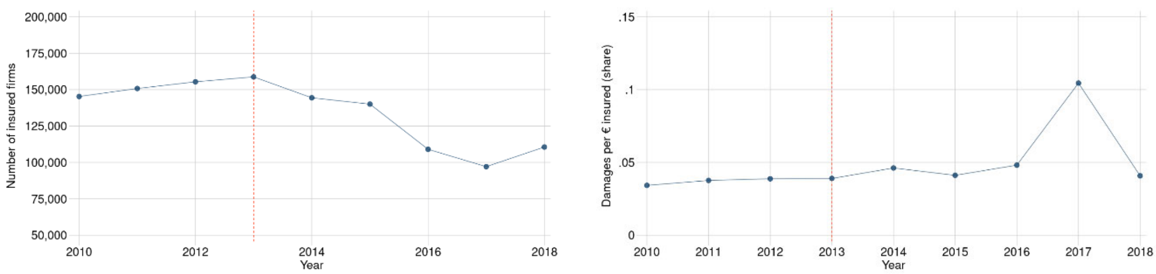
contract. Ideally we would like to carry out an experiment in which half of the farmers (chosen randomly) are offered a low-price contract, and others the same contract at a higher price. If there is adverse selection, we would expect to see more compensation among those who paid the most for the contract. The fact that the two samples of farmers are randomly selected ensures that the characteristics of the two groups, for example in terms of exposure to climate risks or financial education, are similar.

Since we cannot conduct a real experiment, we have exploited a 'natural experiment', namely a historical episode that replicates the conditions of a controlled experiment.[4] We took advantage of the fact that in 2014, a European Regulation lowered the cap on state subsidies to the insurance premiums that farmers could receive (from 80 to 65 per cent of the premium). This change meant that farmers who insured before 2014 paid on average a *lower* price than those who insured after 2014. In the event of adverse selection, it is reasonable to think that the average costs for insurance companies have therefore risen since 2014. Those who were willing to insure even after the reduction of subsidies had to be riskier and this leads to higher disbursements for compensation by insurers.

This is exactly what we find in the data. In Figure 2.1, we show the evolution over time both in the number of insured companies and of the average disbursements on the part of insurance companies following extreme events. Two facts clearly emerge from these graphs: (1) the 2014 reform is associated with a sharp decline in the number of insured companies (from around 160,000 to 100,000 companies, a 37 per cent decrease); and (2) the disappearance of 'less risky' companies has raised average disbursements for compensation from insurance companies. The growth of average disbursements is less evident in raw data because extreme events are still rare and because 63 per cent of companies remain insured both before and after, but more in-depth econometric analyses confirm these developments.

Figure 2.1 Evolution over time of the number of insured enterprises and of the average disbursements

Number of agricultural holdings insured — Value compensated per euro insured (€)



(1) Authors' calculations based on *SicurAgro* data.

To be sure of our results, we tried to perform an additional test based on very similar ideas. Before the 2014 Regulation, not all Italian municipalities had the same level of insurance coverage. If the average risk does not vary with the price farmers are willing to pay, i.e. in the absence of adverse selection, we should not find any correlation between the initial share of insured farmers and the evolution of average post-reform disbursements. When we relate the two things, however, we find exactly the opposite: municipalities that saw a greater decline in the number of insurances due to the reform subsequently saw a greater increase in average disbursements (per firm). This is an additional sign of the presence of adverse

[4] The use of natural experiments in economic research was awarded the Nobel Prize in 2021, won by economists Joshua Angrist, David Card and Guido Imbens.

selection. Not only do both analyses show the presence of adverse selection, the results are also quantitatively similar: a decrease in the share of insured companies of 10 percentage points is associated with an increase in compensation for the insured company of between 0.3 and 0.5 cents per euro of insured value. Although this amount may seem very small, the average disbursement over the time horizon considered is 4 cents. Thus, in percentage terms, the increase of half a cent corresponds to an increase of 12.5 per cent.

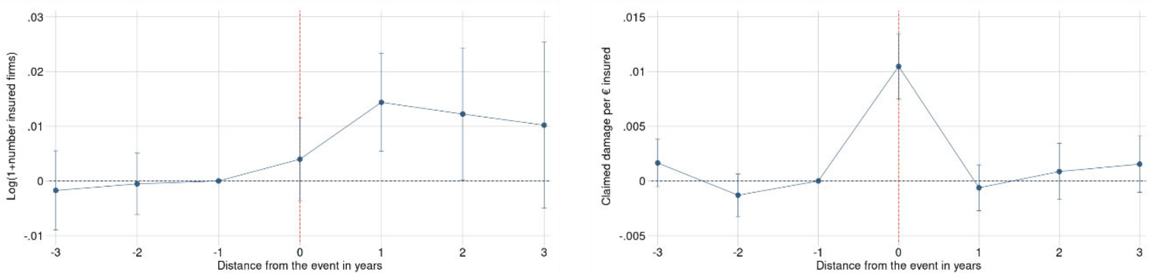
We now describe how we tested the presence of frictions on the demand side. Let us start from the assumption that finding this phenomenon in the data is conceptually difficult. Establishing the presence of an error of judgment by farmers presupposes the definition of an 'exact' answer, which can vary from individual to individual. As long as we do not know exactly what the objectives and tools available to farmers are, we cannot say with certainty that they are making suboptimal choices.

To address this measurement problem, we have adopted an *indirect* test, which uses the following idea: if farmers already had all the information about their riskiness and risk aversion and were already making optimal decisions for themselves, then specific occurrences of extreme weather events should not make farmers insure to a greater or lesser degree. After all, that risk had to be incorporated into their choices to start with. Changing one's opinion about insurance immediately after an extreme event denotes a lack of complete awareness of risks or preferences regarding insurance.

The practical application is quite intuitive. We studied the evolution of insurance coverage at municipal level around the dates of all the extreme events recorded in the ESWD database that took place in Italy between 2012 and 2018. When we study strong hailstorms, the type of event most frequently insured against, our econometric analyses reveal a strong statistical regularity (see Figure 2.2).[5] While insurance coverage does not follow any particular trend in the years preceding the extreme event, it responds clearly the year after the event, remaining higher even in the following years. By studying the evolution of average compensation, we find another interesting phenomenon: although they show a sudden increase in the year of the event, they return to previous levels in the following years. Those who buy insurance contracts following the extreme event are therefore not adversely selected. It should be pointed out that reacting to the extreme event is not necessarily irrational behaviour. It may indicate a form of learning, but the substance does not change: if the farmer is in the process of learning, it means that they were not fully informed beforehand about the climate risk against which they could be insured.[6]

Figure 2.2 Insurance values and average disbursements following strong hailstorms

Number of agricultural holdings insured *Value compensated per euro insured (€)*



[5] This statistical regularity is not observed for heavy rains or strong winds.
[6] Our test does not allow us to distinguish between the various types of 'frictions' highlighted in the literature, but it does allow us to determine the presence of a non-full awareness of the risks.

(1) Econometric estimates on *SicurAgro* data. Log indicates the natural logarithm function. For more details on the estimation procedure, see Citino *et al.* (2021).

Conclusions. — In our work, we used data at municipal level on insurance and extreme weather events to identify the possible presence of adverse selection and 'frictions' on the demand side in the market for agricultural insurance in Italy. Our analysis indicates that both of these inefficiencies are present. Giving precise guidance on the economic policies to be adopted would require more in-depth analyses, measuring the monetary value of the costs arising from these inefficiencies, as well as numerous other quantities, on which we do not focus. These more complex analyses cannot disregard the use of (micro) individual data, unfortunately not available to us. The use of these data would not only allow a better description of the phenomenon, but also a precise measurement of the pros and cons of the different policies, not obvious a priori.

Qualitatively, it is possible to state that demand-side frictions in a market with adverse selection make premium subsidies (already widely used in Italy) less effective and more expensive. In this context, it would at least be desirable to open the discussion to the use of alternative instruments, such as the imposition of compulsory insurance, as is the case in other markets.

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3. THE ROLE OF THE COMMON AGRICULTURAL POLICY IN ADOPTING RISK MITIGATION STRATEGIES BY ITALIAN FARMS

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Classification of JEL: Q18, Q54.

Keywords: agricultural policy; climate, natural disasters and their management, global warming.

Introduction. — Our planet is facing the great challenge of climate change. Southern Europe and the Mediterranean are among the areas most vulnerable to climate change, also due to the high anthropogenic pressure on natural resources.

The agricultural sector is particularly exposed to the changing climate: the reduction in precipitation, the increase in maximum temperatures and the greater frequency of extreme events could cause a reduction in the yield of certain crops and a change in the areas where traditional crops are cultivated, with a possible move to northern areas with a less adverse climate. Due to climatic-meteorological alterations, agricultural production will be increasingly affected by frosts, storms, epizootic diseases and droughts. Therefore, farms will have to implement strategies to adapt to climate change, including with the support of public policies, through technical innovations (e.g. crop diversification for increasing biodiversity and improving soil quality and drainage capacity; the use of physical structures to protect crops; improving the efficiency of irrigation systems; the introduction of water storage systems) but also by adopting risk management practices (e.g. through diversification of revenue sources and/or by adhering to insurance coverage systems) to limit losses caused by adverse weather events.

This study (Bottoni *et al.* 2022) seeks to identify the response of Italian farms to the dynamics of climate change over the last decade, assessing whether the Common Agricultural Policy (CAP), in force in the seven-year period 2014-2020, has played an important role in encouraging such behaviours and adaptation strategies.

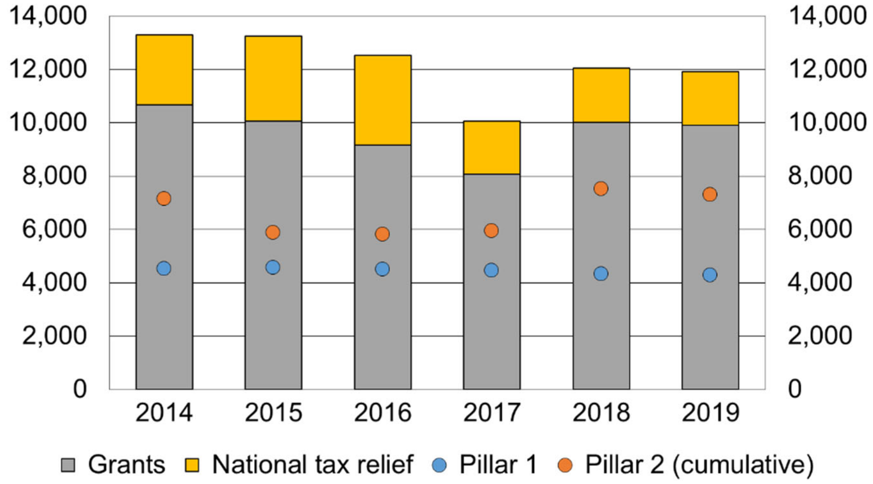
The CAP is the main public financing instrument for the agricultural sector (Figure 3.1); in the period 2014-2019, it allocated €12.2 billion per year to the Italian agricultural sector on average. The CAP is based on two pillars: the first, which accounts for approximately three quarters of the total funding of the programme, provides direct farm income support and market support measures, with broad access requirements. The second pillar finances rural development and is divided into 20 specific measures, among which Member States choose to draft their own Rural Development Programmes to be implemented during the seven-year programming of the European Union budget; it has a higher level of flexibility and is co-financed by individual programmes at regional and national level. The rural development policy financed by the second pillar of the CAP is an integral part of the European Strategy for Adaptation to Climate Change (EC SWD (2013) 216 final), which gave all the measures a potentially leading role in increasing farm resilience against climate change impacts (EC SWD (2013) 139 final). Moreover, as of 2014, a substantial part of Pillar II funds were expected to be allocated to encourage investment in environment and climate, forest

[1] Bank of Italy —Venice branch.
[*] Bank of Italy —Venice branch.
[2] European Commission, Joint Research Centre.

development, organic farming and crop protection, with the ultimate aim of making the agricultural system more resilient to climate change.

Figure 3.1 Composition of annual subsidies granted to Italian farms

(millions of euros)



Source: Our calculations based on CREA data.

While the concept of resilience is complex and difficult to measure[3], production strategies for risk mitigation and business robustness in the short and medium term can be identified. The agricultural literature mainly refers to the following types of such strategies: (i) diversification (of production or of work outside the farm), (ii) price risk transfer (e.g. clauses in commercial contracts); (iii) the transfer of the agricultural harvest risk through insurance policies (van Asseldonk *et al.*, 2016); and (iv) the enhancement of specific production inputs that protect production from possible damage, such as irrigation systems in place of traditional non-irrigated systems (Kurukulasuriya *et al*., 2006) and pesticides to cope with the growing pest threat (Delcour *et al.* 2015).

In light of these considerations, in order to investigate the role of public support for agriculture in improving the resilience of the Italian agricultural system to the consequences of climate change, in our study, we focused on the funds provided through the second pillar. We also focused on some specific adaptation strategies that can be identified in the data available to us: (i) investments in crop protection systems, such as pesticides; (ii) expenditure on premiums for insurance against crop damage; (iii) expenditure on irrigation; and (iv) the share of revenues from other gainful activities, which quantifies the extent to which farms are diversifying their production activity.

The previous empirical literature focused on analysing the determinants of adopting risk management strategies or on estimating the impact of climate shocks on other farmers' adaptation strategies. Several studies provide evidence of the correlation between certain characteristics of a farm (including size and access to credit) and of farmers (including age

[3] Referring to three key concepts relating to risk management, Meuwissen *et al.* (2019) define the resilience of an agricultural system as 'its ability to ensure the provision of the system functions in the face of increasingly complex and accumulating economic, social, environmental and institutional shocks and stresses, through capacities of robustness, adaptability and transformability'. Robustness means the ability to withstand stress and (un)predicted shocks, while maintaining previous functionality levels without substantial changes to the original elements, while adaptability implies changing input composition, production and risk management in response to shocks and stress. Finally, transformability involves a significant change in internal structures and processes.

and education) and the adoption of risk management strategies, such as insurance and diversification of productive activities (Asfaw *et al., 2018*, Bartolini *et al.* 2014; Bozzola *et al.*, 2018; Falco *et al.* 2014; McElwee and Bosworth, 2010).

In the agricultural context, few studies have highlighted how public policies can play an important role (see Termeer *et al.,* 2018, for a broad discussion on the subject). Public funding may support or limit the resilience capacities of agricultural systems, depending on its formulation and the incentives provided (e.g. government compensation for losses can contribute to business robustness in the short term but may incentivize inertia and weaken their adaptability and transformability in the longer term; see Annan and Schlenker, 2015 for the United States). However, the existing literature has not reached a consolidated consensus on the real effectiveness of the current EU agricultural policy in influencing the adoption of adaptation practices and the resilience of European agricultural systems. In general, the literature quantifying the impact of public policies on agricultural practices is hampered both by the complexity of their design — including the multiplicity of measures in place — and by territorial heterogeneity.

Data and outlines of empirical strategy. — We carried out a counterfactual econometric analysis to identify whether the presence of CAP subsidies favoured the adoption of selected adaptation strategies by Italian farms. Several databases have been combined: (i) the information on Italian farms collected through the CREA Agricultural Accounting Information Network (RICA); (ii) the European Severe Weather Database, which is compiled by the European Severe Storms Laboratory and includes geolocalized information on extreme weather events (e.g. hailstorms or flooding); and (iii) the dataset on the Standardised Precipitation Evapotranspiration Index (SPEI), a climate index that measures deviations from the long-term hydroclimate balance (Vicente-Serrano *et al.* 2010).

The Farm Accountancy Data Network (FADN) database contains detailed information on a representative sample of Italian farms, chosen annually through a random sampling method, which takes into account the different types of farms in Italy, and their size and geographical location. For our analysis, we drew on the following key information: the economic and financial variables (including transfers received from the second CAP pillar and insurance expenditure), information on inputs used (e.g. work, irrigation, fertilizers, crop protection expenditure) and the characteristics of the agricultural entrepreneur (age, level of education and gender). We focused on farms growing crops, excluding those specialized in breeding, and we restricted the sample to farms for which the information on all the variables used in the analysis were present in the period 2013-2019 (approximately 12.5 per cent of the initial sample). Finally, our analysis only includes farms that received a positive amount of subsidies from Pillar 2 in the period 2014-2019. The final sample consists of 1,320 observations, distributed over 825 Italian municipalities and in all 21 Italian regions. Compared with the reference population, consisting of the universe of farms operating in Italy, our final sample tends to over-represent large farms, both in physical and economic terms, and farms located in the northern part of the country.

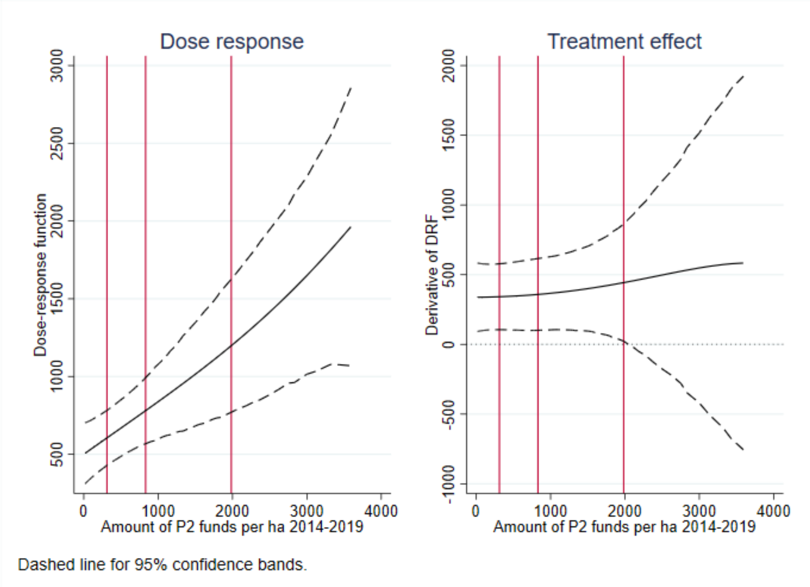
The second pillar of the CAP includes a variety of different programmes and measures, with very different rules and eligibility requirements, which also vary across different administrative areas. These conditions do not make it possible to identify a clear discontinuity (e.g. in the characteristics of companies that can access the funds, or in the amount paid according to the precise policy design) that can replicate the conditions of a laboratory experiment, which would have made it easier to assess the quantitative impact of the policy.

In order to correctly measure the causal impact of the amount of funds received from Italian farmers on the outcomes of interest discussed above, we adopt an empirical methodology aimed at correcting the distortion of the estimate due to the fact that the allocation of funding is not random, but rather linked to the same characteristics of the farms that also impact the outcomes. For example, we can expect that the age (education) of an agricultural entrepreneur is negatively (positively) correlated with the ability of a farmer to apply for and obtain Pillar II funds; at the same time, previous literature has shown that younger and more educated farmers are more likely to diversify production activities. In addition, we are interested in estimating the heterogeneity of treatment effects resulting from the change in the exact amount of CAP Pillar II funds received.

We adopted an econometric methodology (Generalized Propensity Score) that makes possible a robust counterfactual analysis between comparable sub-samples. In order to assess the existence of a CAP effect on the adoption of the adaptation strategies described above, the econometric methodology adopted compares groups of agricultural holdings that received different amounts of transfers from the second pillar of the CAP in the period 2014-2019 and that are very similar in their characteristics, as measured prior to the receipt of the 2014-2019 CAP pillar 2, i.e. in 2013. It is therefore possible to map the causal relationship between the amount of funds received and the adoption of the single risk mitigation strategy, at the same level of baseline farm characteristics. In order for the comparison to be valid, the following assumptions must be verified: (i) the selected baseline variables are the only ones to influence the relationship being analysed; and (ii) with similar values for the existing characteristics, there are always farms with substantially different amounts of transfers received. With regard to the first condition, thanks to the richness of the data used, we are able to include a large set of variables in the analysis that, if omitted, would cause distortions in the estimates; these variables include characteristics of the farm and the head of the holding, extreme climatic events taking place in the municipality where the holding is located and in the neighbouring municipalities, and the fixed effects of the geographical area (defined by administrative region and eco-region of localization). In order to comply with the second condition, 183 observations were excluded from the analysis.

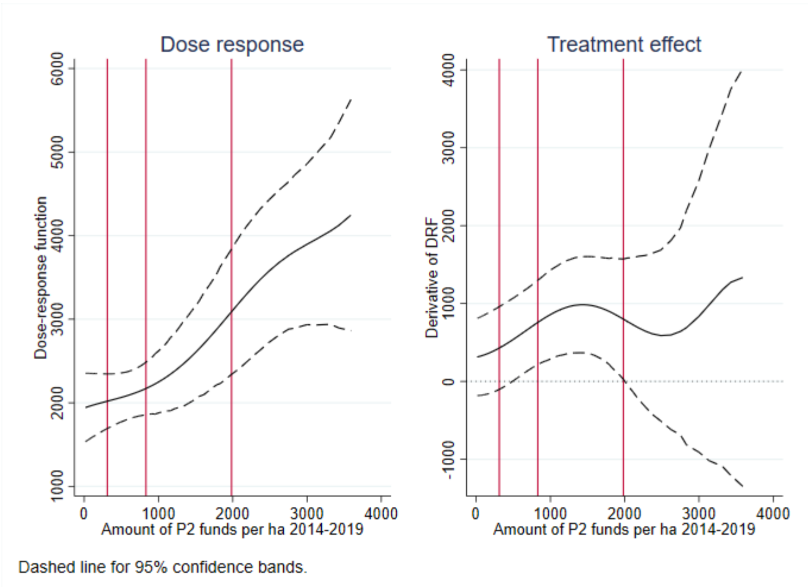
Results and conclusions. — The main findings of the study concern the identification and the form of the causal relationship linking the intensity of funds received through the second pillar of the CAP to farms' responses in implementing the four adaptation strategies listed in the introductory section (Figure 3.2-3.3, left-hand side). It is therefore possible not only to identify whether the funds have an impact on adaptation behaviour, but also to study the magnitude of the impact for different initial amounts of transfers (Figure 3.2-3.3, right-hand side). The latter is achieved by estimating the change in outcome that would be caused by an increase of €1,000 in Pillar II funds relative to different initial amounts of transfers (Figure 3.2-3.3, right-hand side). The vertical lines represent the amounts of funds per hectare received corresponding to the 25th, 50th and 75th percentiles of the distribution within the sample.

Figure 3.2 Results of GPS estimates on insurance expenditure



Source: The 95 per cent confidence interval is indicated by the dotted lines.

Figure 3.3 Results of GPS estimates on crop protection



Source: The 95 per cent confidence interval is indicated by the dotted lines.

The results document that, all things being equal, CAP Pillar II transfers have a positive and statistically significant impact on the expenditure on insurance policies premiums (Figure 3.2). The right-hand graph shows that the effect tends to increase weakly with the level of subsidies. Focusing on the magnitude of estimates, for every extra euro of subsidy (per hectare) received on average over the six years, 36 cents are spent on taking out a crop insurance policy. As far as crop protection expenditure is concerned, it is noted that a higher amount of funds received is associated with increasing expenditure on crop protection (Figure 3.3, left-hand graph). The estimation of the marginal effect (right-hand graph) is sufficiently accurate (in statistical terms) in the range of treatment levels from €514 (35th percentile) to €1,983 (75th percentile). Moreover, additional funds are used for the purchase of protective products for crops, first at an increasing rate and then, for subsidy values greater than €1,451 (65th percentile of distribution), at a decreasing rate. Overall, the marginal effect only varies to a small extent, remaining between 50 and 81 cents per euro (per hectare) received. Additional results show that CAP Pillar II subsidies have no effect on the cost of water expenditure and the increase in the share of revenues from other activities observed between 2013 and 2019 (Figure omitted for brevity).

The study has some empirical limitations. Although the counterfactual methodology is based on a rich set of characteristics and conditions that mitigate endogeneity problems, the internal validity of the results could be threatened by the existence of unmeasured factors. In particular, if there are local economic shocks that lead to changes in local input prices, thus influencing both the propensity of companies to resort to public subsidies and the production choices analysed in this study, the estimation of the causal impact of interest could be biased. However, by measuring cumulative inputs and outcomes over a 6-year period and including regional fixed effects, the potential statistical distortion resulting from short-term changes in price levels to which farms located in the same area are exposed is limited. Another limitation of this study is the focus on measures that limit the damage linked to climate change in the short term and for the individual farmer, but that are not necessarily sustainable in the long term, such as the use of pesticides. As far as external validity is concerned, it is worth pointing out that our results are obtained from the analysis of a selected sample of farms with specific characteristics, i.e. medium to large enterprises which are beneficiaries of Pillar II measures. Therefore, our results may not be reflected in the behaviour of the farms that are representative of the Italian agricultural system. Overall, the results have some limitations but provide an important indication and set the stage for future research on this topic. The empirical analysis shows that the second pillar of the CAP incentivized Italian farms in the period 2014-2019 to undertake certain strategies to adapt to climate change, specifically investments in crop protection and the underwriting of insurance policies against crop damage. The marginal effect of the amount of public funds appears to be relatively stable, indicating that the adoption of adaptation strategies identified in the study is only moderately sensitive to the intensity of the subsidies received. This implies that the empirical analysis has identified neither an optimal level of public support beyond which the disbursement of additional funds is inefficient nor the clear existence of a trade-off between the incentive to adopt 'passive' instruments that protect income stability in the short term (such as insurance tools) and the incentive to adopt 'proactive' instruments that improve the ability of the farm to react to extreme climate events in a more stable way, in the medium term (such as investment in crop protection).

These results provide some initial first evidence, based on national data and robust econometric methods, on the role of public support for agriculture in influencing the adoption of climate change adaptation strategies by Italian farmers. With more detailed information on farmers' productive choices, the analysis could be extended to considering other types of adaptation strategies, such as replacing traditional crops with crop varieties more resistant to climate change. In addition, the availability of data for a longer period could enable the joint assessment of the impact of public support on the adoption of risk management practices in the short and medium term and on the economic resilience of farms in the long term, allowing for more detailed reflections on the trade-off between the benefits of such practices over different time horizons.

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4. BUSINESS DEMOGRAPHY AND MARKET STRUCTURE IN A CHANGING CLIMATE

Michele Cascarano, Filippo Natoli and Andrea Petrella*

Classification of JEL: D22, R12, Q54

Keywords: climate change, temperatures, business dynamics, business demography.

Introduction. — Various scientific studies on the economic effects of climate change have questioned how temperature fluctuations and extreme events, such as heat waves, affect business performance (Addoum *et al.,* 2020). High temperatures can increase sick leave from work and reduce the productivity of workers employed in tasks exposed to atmospheric events (in the open air or in places without air conditioning; Somanathan *et al*., 2021) and, in general, increase overall production costs. In the short term, these phenomena are able to adversely affect the operations of companies. However, the consequences of rising temperatures are more uncertain over a longer period of time: some companies may implement strategies to adapt to high temperatures, introducing technological improvements that could increase their productivity; others may experience persistent production damage from prolonged exposure to unfavourable temperatures, which could eventually hurt their profitability. These different consequences might reverberate and significantly alter their production structures (Albert *et al*., 2021; Pankratz and Schiller, 2021).

In our work (Cascarano, Natoli and Petrella, 2022) we investigate whether climate change (in particular the increased frequency of extreme temperature episodes) can affect companies' decisions to enter and exit the market, or to vary the localization of their activity (overall, we refer to these choices with the expression 'business demography'). In order to investigate the mechanisms through which temperatures affect business activity, we also analyse the effects that heat waves have on the results and profitability of companies that do not leave the market, or at least that remain there for a sufficiently long period of time.

The data. — To measure the trend of extreme temperatures in Italy, we used the Monitoring Agricultural Resources database produced by the Joint Research Centre of the European Commission (JRC MARS), which contains detailed information on daily climatic variables since 1979. We measure the incidence of extreme temperatures in each year, from 1993 onwards, counting the number of days in which the maximum temperature exceeded 30 °C. The choice of this temperature threshold is supported by a series of studies (Bauer *et al., 2019*), which show that the individual productivity of workers drops sharply above this level.[1] The number of days with extreme temperatures has increased significantly in Italy, from just over 20 days in the early 1990s to almost 40 in recent years (Figure 4.1). The analysis of the impact of temperatures on business activities is carried out at local labour market level, using the classification of the national territory into Labour Market Areas (*Sistemi Locali del Lavoro*, SLL).[2] According to this breakdown, the distribution and

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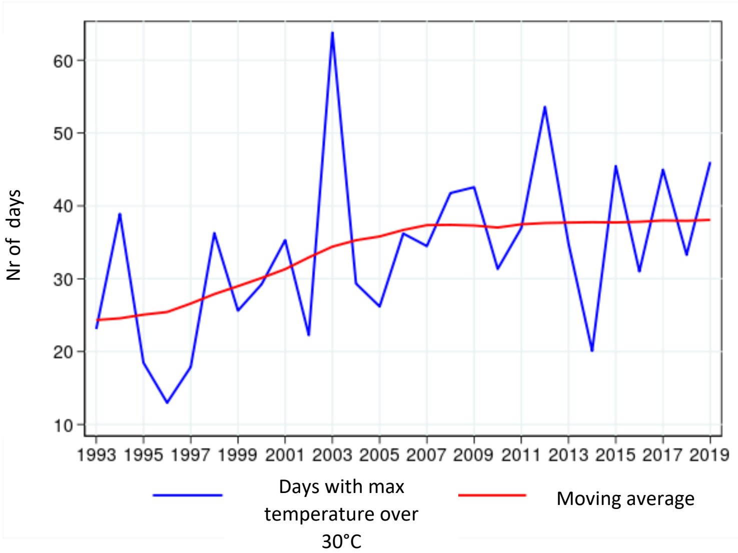
[1] Our results are robust to the variation of this threshold.

[2] The Labour Market Area (SLL) is defined as the geographical unit that contains most of the commuting flows between home and work. It is therefore the territorial unit in which the population exercises most of its social and economic relations and enterprises participate in the labour market, hence the most granular and appropriate observation unit for investigating economic phenomena such as those we intend to examine.

dynamics of extreme temperatures were extremely heterogeneous during that period (Figure 4.2).[3]

Figure 4.1 The evolution of extreme temperatures in Italy

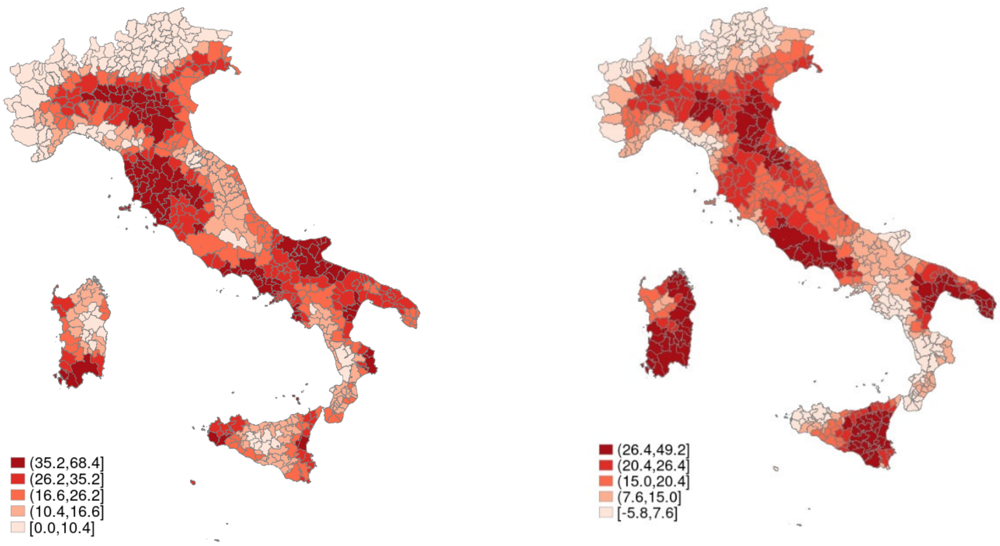


On the business demography side, we have used the Infocamere administrative register on the universe of Italian companies, available from 2005 until 2019, which allows us to identify the date and place where a company starts or ends its business, as well as to keep track of any changes in a company's location. The growth rate of the companies active in each SLL can be broken down as: entry rate-exit rate+net relocation flows to and from the SLL.[4] The entry rate fell sharply on average, especially in the second half of the 2000s (Figure 4.3). On the other hand, the exit rate has grown slightly, while still remaining below the entry rate, implying a growth of active firms throughout the years. Relocation is not quantitatively relevant.

[3] SLLs with a higher frequency of extreme temperatures are not entirely concentrated in southern Italy, which is warmer on average (Figure 4.2.a), but can also be found in some areas of central and northern Italy, in particular Tuscany and vast stretches of the Po Valley. Mountain SLLs are obviously less affected by the phenomenon of heatwaves. During our observation period, the variation in the incidence of extremely hot days was also highly heterogeneous among SLLs (Figure 4.2.b), displaying higher values in Basilicata and southern Puglia, eastern Sicily and Sardinia.
[4] The entry rate is defined as the ratio between the number of firms entering the market and the number of active firms. The other addends of the sum are defined in a similar manner.

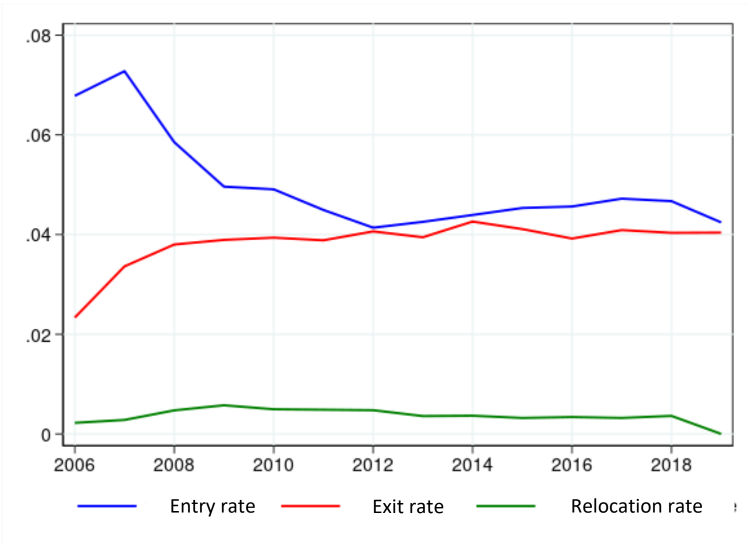
Figure 4.2 Number of days with extreme temperatures

(a) Number of days above 30°C, 1993-97 *(B) Changes between 1993-97 and 2015-19*



The accounting identity between the growth rate of the active companies and its components allows us to reconstruct the channels through which heat waves affect all the active companies in the market. The relationship between extreme temperatures and business fundamentals is examined using a similar methodology.

Figure 4.3 Business Demography in Italy



The effect of temperatures on businesses. — To isolate the effects of extreme temperatures on business demography, we aggregate data at SLL level over three-year periods in order to minimize the short-term variability of our variables. We estimate how much every demographic variable is influenced — in each of the three previous periods — by the change in the number of days with maximum temperatures above 30°C. The parameters estimated with this model (distributed lag model) can be interpreted as the evolution of demographic variables over time, in response to a permanent increase in extreme temperatures.

To avoid confusing the estimated effect with that of other atmospheric phenomena relating to temperature changes, we also include the dynamics of precipitation and the occurrence of other extreme events (such as hail or avalanches) recorded in each SLL in our model.

The results of the estimates show that a permanent increase in extreme temperatures has quantitatively limited, but precisely estimated, consequences on the production structure. It reduces the growth rate of active companies through two channels: on the one hand, the reduction in the entry rate of new companies; on the other hand, a more modest increase in the exit rate. However, the propensity to relocate economic activity does not appear to be significantly affected by the rise in extreme temperatures. Heat waves are an important factor in explaining the evolution of business demography, also in comparison with other weather events.

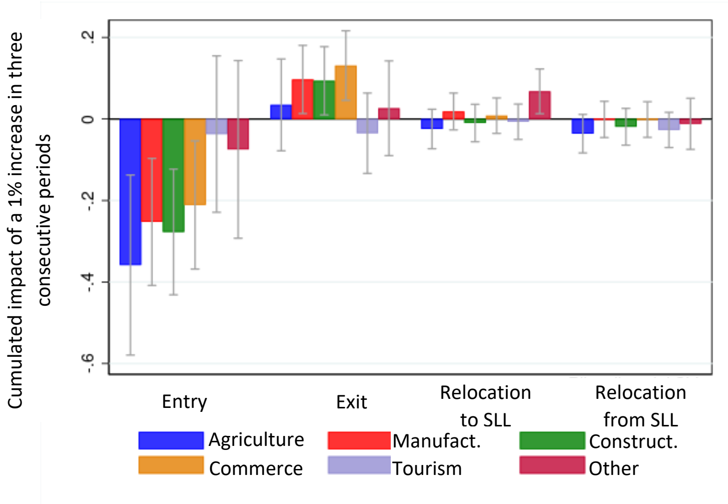
According to our estimates, the average temperature scenario outlined by a consolidated forecast model[5] would result in a cumulative decline in the growth rate of active companies of 0.22 percentage points over the period 2020-31. This figure would consist of a cumulative change of -0.15 percentage points in the entry rate and of 0.09 percentage points in the exit rate. By way of comparison, in our sample, the annual growth rate of active companies, the entry rate and the exit rate are on average 1.53, 5.02 and 3.47 per cent respectively.

The consequences of heatwaves would be more pronounced for SLLs located in the Mediterranean climate zone, which includes the largest islands and most of the coasts and has higher average temperatures. In addition, in line with the evidence from other economic studies (Graff Zivin and Neidell, 2014), the drop in the entry rate and the increase in the exit rate following a rise in temperatures are stronger and more significant for the sectors most exposed to climate change: agriculture, construction, manufacturing and trade (Figure 4.4).

The results mentioned so far show that business demography in Italy is affected by high temperatures, but cannot provide information on the characteristics of exiting companies or potential entrants. To investigate the effect of temperatures on business activity over the medium term, we run additional analyses on companies remaining active over a prolonged period of time, using Cerved Group's data on firms' balance sheets. This information source includes all publicly traded companies and all unlisted limited liability companies, including micro-enterprises and individual workers, and allows us to estimate the relationship between temperature and business fundamentals for each firm size class.

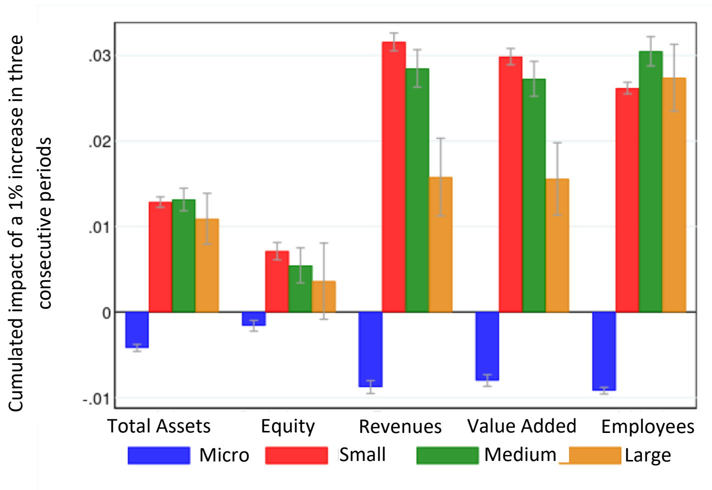
[5] These are the projections of the ETHZ CLM regional climate model of the Swiss Federal Institute of Technology. See Jaeger *et al.* (2008).

Figure 4.4 The effects of extreme temperatures on business demography, by sector



Using this sample, our results suggest that a permanent temperature increase could positively affect net revenues and production of the surviving companies, increasing profitability on average over the long term. This empirical evidence suggests that some companies are able to implement adaptation mechanisms that result in improved business performance. Breaking down the analysis according to firm size, a substantial heterogeneity emerges: while temperatures are positively associated with growth in revenues, production and assets for medium and large enterprises, they show a negative relationship for companies with fewer than ten employees, which reduces long-term investment (Figure 4.5). These results indicate a different resilience capacity to climate change among firms, suggesting that global warming could stimulate a reallocation of market shares within the production system.

Figure 4.5 The effects of extreme temperatures on firm performance by size class



Which policies for businesses? — The results of the analysis show that a permanent increase in the incidence of high temperatures leads to a reduction in the entry rate and a smaller increase in exit rates. The results vary significantly depending on the sector and the area in which these companies are located. The analysis carried out on individual firms' balance sheets shows that rising temperatures also influence the results and profitability of active companies, with a radically different impact depending on their size: the effects are only negative for small businesses, while larger ones seem to benefit from higher temperatures, probably as a result of their greater adaptability.

These results could have significant implications for economic policies. The marked territorial heterogeneity of the effects of extreme temperatures on entry and exit rates could widen the existing territorial gaps (since the Mediterranean climate zone mostly falls in Southern Italy); an improvement in the conditions for doing business in areas most affected by high temperatures could increase the resilience of the local production system to climate change. Moreover, the greater difficulties for smaller companies in adapting to climate change could stimulate a reflection on whether to accompany the adaptation of this category of companies to the new climate trends with targeted support strategies.

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5. FRAGILE TERRITORIES, WEAK COMPANIES

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Classification of JEL: D24, Q54, C21.

Keywords: climate change, natural disasters, floods, landslides, business survival, business growth.

Introduction. — There has been a sharp increase in extreme events dependent on climate change in recent years, with a corresponding increase in the hydrogeological risks caused by changes in precipitation frequency and intensity (Gariano *et al., 2016*, Haque *et al.*, 2016, Hoeppe, 2016). The impacts involved not only the environment and health, but also the economy.

According to the Centre for Research on the Epidemiology of Disasters (CRED), between 1998 and 2017, hydrogeological events, particularly landslides and floods, resulted in more than 160,000 deaths worldwide, with economic losses estimated at $660 billion (UNISDR-CRED, 2018). Floods are the most frequent type of climate-related natural disaster, accounting for about 43 per cent of the events in the period 1998-2017. A report by the Swiss Re insurance group shows that the flood that affected parts of Germany and Belgium in July 2021 caused more than $40 billion of economic damage, of which around $13 billion were covered by insurance.[1] The European Environment Agency stressed the importance of losses caused by extreme climate events, especially for the most exposed countries, including Italy.[2]

These trends require a broader understanding of the economic consequences of natural disasters, going beyond quantifying the damage caused by events (direct costs) and further exploring the short and medium-term effects (indirect costs) that depend on interactions between actors within the economic system. It is also important to analyse not only the most striking but also the least extreme events, which are becoming more frequent and widespread.

A territory exposed to risks. — Italy has a high exposure to hydrogeological risks, for both natural and human reasons. From a geological point of view, the Italian territory was formed relatively recently and is tectonically active; moreover, the soils and rocks that make up the mountainous and hilly reliefs are made up to a large extent of weak material and are therefore very susceptible to landslides. The plain areas are instead widely subject to flooding phenomena, and this concerns both the large rivers that flow in the wide floodplains, and the smaller streams, which are often of a torrential kind. In addition to the natural characteristics, there has been intense anthropogenic activity that continues to expand, including in territories exposed to hydrogeological risks.

In the context of global climate change, the Italian situation is characterized by a decrease in total annual rainfall and by a simultaneous increase in the concentration of rain quantities over time, with an increase in both droughts and in extreme events characterized by high rain intensity (Alpert *et al.*, 2002). In other words, if a lower total amount of rain falls

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[1] See https://www.swissre.com/media/news-releases/nr-20211214-sigma-full-year-2021-preliminary-natcat-loss-estimates.html

[2] See https://www.eea.europa.eu/ims/economic-losses-from-climate-related

annually on average, it is concentrated in a few events with extraordinary peaks of precipitation. This change in the rain regime affects the hydro-geomorphological phenomena triggered by rain and thus contributes to a significant increase in landslides and floods.

A critical picture emerges from the combination of natural features and human behaviour: according to recent ISPRA surveys, 12.6 per cent of the population, 14.1 per cent of industries and services and 21.1 per cent of cultural heritage are located in areas officially mapped as highly dangerous from a hydrogeological point of view (ISPRA, 2018). The problem is extremely widespread, given that more than 90 per cent of Italian municipalities have at least part of their territory mapped in the highest hazard category.

The economic consequences of natural disasters. — The economic literature divides the effects of natural disasters into direct and indirect effects. The former are generally negative and include (in addition to victims and injuries) damage to infrastructure, buildings and homes, and loss of physical capital of businesses or inventories. The indirect effects can be both negative, such as those resulting from the interruption of business activities or supply chains, and positive, for example, the sectors involved in reconstruction can experience an increase in production.

Some studies point out that adverse events of a natural origin could accelerate the exit from the market of the most inefficient companies, thus increasing aggregate productivity. Combined with reconstruction funds, these dynamics can foster an economic recovery with more sustained growth rates. In a process of creative destruction, damaged physical capital could also be replaced and upgraded to the best available technologies or replaced by investments in human capital (less exposed to physical risks), with positive growth consequences. On the other hand, the destruction caused by the catastrophe could also trigger a negative economic spiral of capital loss, lower productivity growth and further reductions in investments.

The empirical literature has therefore sought to estimate the 'net' effects of natural disasters and of hydrogeological risks in particular. The first studies, based on macroeconomic data at country level, did not actually provide a unique response (Zhou *et al.*, 2021); more recently, the availability of data at sub-national level, both on economic variables of interest and on event location, has led to studies suggesting mostly negative impacts on local economic growth (Boustan *et al.*, 2017; Strobl, 2011), on household income and spending and on real estate values (Anttila-Hughes *et al.*, 2013). Other studies have focused on the effects of hydrogeological phenomena on business activity, in many cases analysing the impact of individual extreme events (such as Hurricane Katrina or Typhoon Vera). Some papers found positive effects on firms' assets and employment levels (Leiter *et al.,* 2009) or on value added growth (Coelli *et al., 2014*), while others showed that natural disasters affect both the likelihood of firms' survival and the performance of those remaining in business, with heterogeneous effects depending on individual characteristics (Basker *et al.*, 2018; Okubo *et al*., 2021).

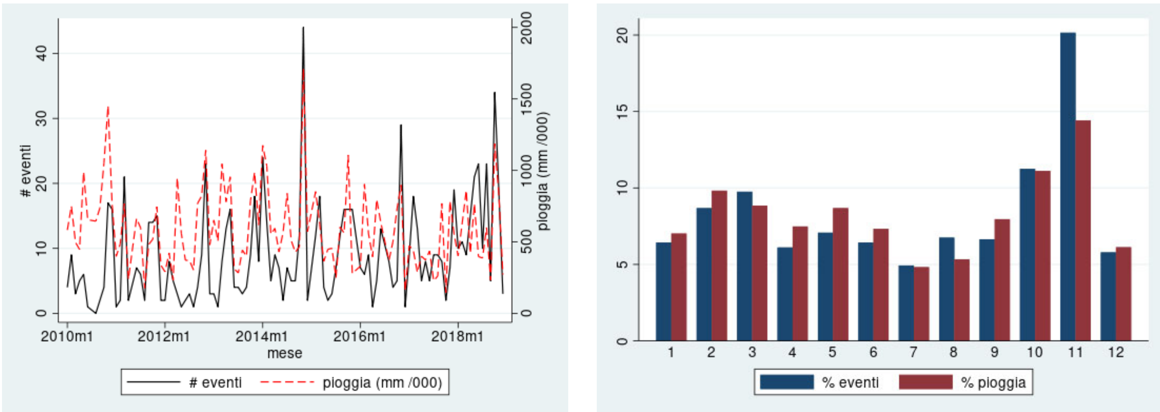
A new database for landslides and floods. — Our research (Clò *et al.*, 2022) focused on the Italian territory with the aim of analysing and estimating the impact of hydrogeological disasters on Italian firms. In particular, instead of focusing on single extreme events, we analyse the impact of a multiplicity of natural events over a multi-year period, the frequency of which is increasing also due to the ongoing climate crisis. This is both a novelty and a contribution to existing literature.

Information on landslides and floods that have affected the Italian territory comes from a database developed by the Department of Earth Sciences of the University of Florence based on an algorithm called SECAGN (Semantic Engine to Classify and Geotag News), which researches and ranks the news of hydrogeological events published on the web. SECAGN constantly scans the Internet, searching for news relating to landslides, floods and similar phenomena, using the information contained in the articles to classify and geolocalize them, typically at municipal level. The database currently covers a period of more than 10 years, starting in 2010, and contains information on the type of event (a landslide or a flood), its location, the date of occurrence, the number of news stories from different sources linked to the same event and a set of variables used to verify the accuracy of the spatial localization and the classification of the news. Compared with other databases on phenomena of interest, SECAGN has above all the advantages of the granularity of its geographical information and of relying on an almost entirely automated procedure, which makes it possible not to depend on the compilation of reports by national or local authorities, insurance companies or on requests for aid for the affected areas.[3]

The figure shows the temporal trend of the events considered[4] in the period analysed (2010-2018) together with that of precipitation. The two variables show a certain temporal correlation, since rain constitutes the 'climate forcing' of hydro-geological events, with a clear seasonality (concentration in the initial and especially the final months of the year).

Figure 5.1 Hydrogeological events and rainfall per month

Number of events and total rainfall | Seasonality of events and rainfall (1)



(1) Percentages of events and amount of rain for each month of the year.

Sources: SECAGN data for events and Agri4Cast for rainfall.

To analyse the impact of adverse natural events on Italian firms, we use company financial statements collected on an annual basis by Cerved Group, providing information on the fixed assets, turnover, size class, NACE sector and location of virtually all limited companies. For each firm, we also know the number of employees (from INPS source) and we estimate its total factor productivity (TFP).

We used an econometric analysis to study whether, compared with companies with similar characteristics but located in municipalities not affected by adverse events, companies in affected municipalities experienced a lower probability of survival in the years following the catastrophe and, for those still in the market, a different economic performance. This

[3] For example, in the Severe Storms and Extreme Events database (https://www.climate.gov/maps-data/dataset/severe-storms-and-extreme-events-data-table), events are detected either by the National Meteorological Services through visual instruments and observations, or through self-reporting techniques, such as information received from observers calling to report serious events.

[4] The analysis focuses on the most severe events, defined as those that generated a number of news stories in the higher decile of the distribution of the number of news stories (scaled for the municipal population). In fact, many events recorded in the SECAGN database have linked news stories at most, and this could indicate a limited media importance for the event and probably, therefore, a reduced intensity of the connected phenomenon.

approach made it possible to estimate the effects of hydrogeological events both on the number of active enterprises (extensive margin)[5] and on the performance of the survivors (intensive margin). The analysis of the temporal change in economic activity before and after the adverse event carried out on companies located in the affected municipalities compared with those operating in municipalities not hit by natural disasters allows us to disentangle the impact of catastrophic events on business performance from other possible variables affecting their performance.

Fewer businesses, less turnover and employment. — A first result of our analysis is that companies located in municipalities affected by landslides or floods have, on average, experienced a 4.8 per cent higher probability of exiting the market with respect to non-affected firms.[6] The effect is concentrated on micro- and small enterprises, while it is not significant for medium to large enterprises.

With reference to the performance of the surviving companies, in the three years following the shock, revenues and employees are on average 4.2 and 1.9 per cent lower respectively compared with a counterfactual scenario with no landslides or floods. The decrease in turnover occurs from the year in which the adverse event occurs, that of the number of employees from the following year. The effects continue in the following years, but are eventually absorbed after about 4-5 years.

Further analysis shows that the negative impact of these phenomena is concentrated on smaller companies and on construction and services companies, probably because a large part of their activity is linked to the physical accessibility of workplaces. Geographically, the impact is more pronounced in the Mezzogiorno region and in rural areas. Although it is not strictly the subject of this study, it should be noted that this latter aspect can further accelerate the depopulation processes that affect many areas in Italy's hinterland, which often end up making them even more fragile and exposed to natural events.

Among the phenomena considered, it is floods above all that affect the activity of firms. The negative impact is similar between the areas that ex-ante were most exposed to this type of risk and those that were less exposed; it can therefore be assumed that there is no significant awareness of the economic effects of hydrogeological risks or any adequate preparation and investment in adaptability to this type of shock, even in the most exposed areas. Action should therefore be taken to contrast the intensification of hydrogeological events through a combination of mitigation, adaptation, prevention and protection policies.

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[5] The extensive margin analysis focuses solely on outgoing companies, while it is not possible to obtain information on companies potentially interested in entering the market and assessing the effect of landslides and floods on this choice.
[6] In the average period, the probability of exiting the market in a given year is 4.8 per cent for the affected companies and 4.6 per cent for the others.

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6. CLIMATE CHANGE AND WINTER TOURISM IN THE ALPS

Gioia Maria Mariani* and Diego Scalise*

Classification of JEL: Q51, Q54

Keywords: climate change, winter tourism.

Introduction. — Climate change will have significant repercussions on the tourism industry in Italy, especially in its mountain sector, which risks being most exposed to rising temperatures and declining snow precipitation, a fundamental condition for practising winter sports, which is a decisive factor for Alpine resorts.

Mountain tourism is one of the main segments of the Italian tourism sector: before the outbreak of the COVID-19 pandemic, about 13 per cent of the overnight stays in hotels in Italy were concentrated in mountain resorts and the spending of foreign travellers in these was about €2 billion (out of a total of over €28 billion). Many tourists are attracted to the possibility of practising winter sports, which depend on the frequency and reliability of snowfall. At the same time, the Alpine range will be one of the areas where the increase in temperatures will be more intense, up to three times higher than the average of the northern hemisphere:[1] the higher average temperatures, as well as the decrease in snowfall, would compromise the usability of ski lifts and reduce the attractiveness of mountain resorts. The impacts could be particularly severe in a context where economic activity is poorly diversified and very geographically concentrated.

In a recent work (Mariani and Scalise, 2022), we attempted to quantify the effect of climate change on tourist flows to Alpine resorts in the winter season, focusing both on the number of passes for the lifts and on the number of overnight stays in the Alpine municipalities. The use of two outcome variables allows us to analyse two different phenomena: the use of the facilities is indicative of how the climate conditions allow people to practise winter sports, while the overnight stays capture the demand for tourism in a wider sense and also reflect the ability of a locality to attract tourists also thanks to other amenities.

The study fits into the recent literature on estimating the impacts of climate change on the tourism industry. The analyses have so far focused mainly on the relationship between climate change and tourism demand throughout the year, while estimates on the specific winter segment are still limited: in Falk (2010), there is a review of the literature, which has so far focused on two different strands, looking at both the effect of changed environmental conditions on the tourist supply and the changes in demand in response to the latter. In the same study, the authors estimate a positive relationship between snow conditions and overnight stays in Austrian ski resorts, which are greater for low-altitude resorts. With regard to Italy, some studies in the absence of more granular data looked at the number of overnight stays at regional level and found a negative impact of global warming (Bigano *et al.*, 2006). The effects would be more intense in areas of lower altitude, where the snow cover necessary for the operation of the ski lifts would not be guaranteed: in particular, Abegg *et al.* (2007)

* Bank of Italy.

[1] Declaration by the Ministers of the member countries at the end of the 2006 Alpine Conference. The Conference is the supreme body of the Alpine Convention, established in 1991 among the countries located in the Alpine region in order to implement a common policy of mountain protection and development. The Ministers responsible for the Contracting Parties and their delegates normally meet every two years. Their meetings are chaired by the Contracting Party holding the Presidency of the Convention. As a political and decision-making body, the Alpine Convention discusses its objectives and determines the policy measures to be implemented.

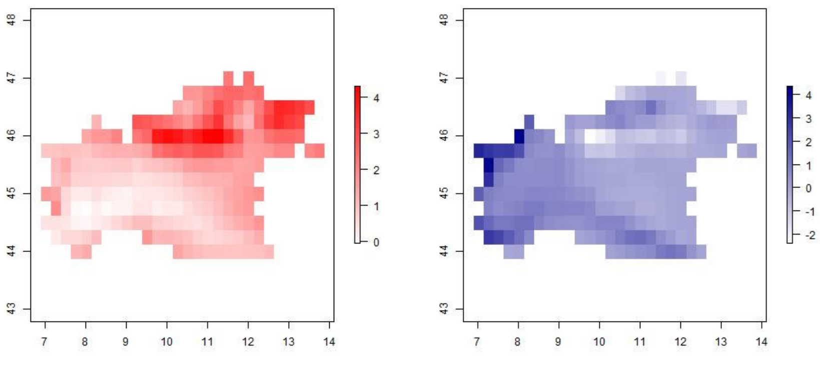
estimate that an increase of 1°C in temperature would be sufficient to raise the reliability line of snow on the Alps until all the ski resorts in Friuli-Venezia-Giulia and about 30 per cent of those in Veneto, Lombardy and Trentino are no longer viable.

Thanks to the use of data at the level of the tourist area, our study aims to provide more precise evidence of the damage to some regions of northern Italy: by analysing the impact on the number of passes in ski resorts in a given season, the work focuses on the part of tourist demand that, being mainly linked to winter sports, responds more promptly to changes in climatic conditions. The analysis of overnight stays allows us to study the loss due to the less elastic demand because of climate conditions, also offering evidence to support the importance of diversifying what is on offer to tourists in terms of activities other than downhill skiing.

The data: climate change in the Alps. — The dataset we have built contains information on overnight stays and the use of ski lifts for the tourist resorts of Valle d'Aosta and Trentino Alto Adige over a period from 2001 to the 2018-2019 winter season, so as to exclude the period of the start of the COVID-19 pandemic. The source of the data is the regional statistical offices. The availability of the data does not allow us to investigate the effect on the entire Alps, but the regions under analysis account for more than two thirds of the total overnight stays associated with mountain tourism. In addition, by comparing locations that are quite distant from each other, it is possible to exploit a sufficient variation in the climate variables for the purpose of estimating the effect we are interested in. The source of the climate variables is the Copernicus database, created on the initiative of the European Commission, which provides information on average ground temperatures and snow precipitation rates: from these data we obtain the amount of snow falling during the period under analysis (according to the dependent variable, the entire winter season or the month). During the period observed, the average temperature during the season increased significantly, especially in the areas of the north-east of Italy, where the altitude is lower: in the same area, there was also a decrease in the amount of snow falling.

Figure 6.1 Difference between the winter seasons of 2001 and 2019

(temperature (°C) and metres of snow)



Source: Calculations based on Copernicus data.

Using ISTAT context data on the accommodation offered by municipalities, their altitude and distance from urban centres and the presence of cultural or alternative attractions to sport, the observable characteristics of the area are included in the analysis, so as to check for possible sources of heterogeneity in tourist demand. Resorts in the Valle d'Aosta are at a higher altitude, tend to have fewer inhabitants and consistently have a more limited offer focused on winter sports relating to snow. The analysis also takes into account the cultural offer, which could affect the choice of destination by tourists, the average distance from a large city and the economic structure of the municipality, indicated by the share of employees in the commercial sector.

Methodology and results. — Our estimates use both the temporal and spatial dimensions of the database to quantify as precisely as possible the effect of climate variables on tourist flows, taking into account the observable and unobservable differences between areas. In particular, the panel model with fixed effects allows us to estimate the relationship between climate conditions and tourist flows net of the fixed time characteristics of the areas, such as the altitude or latitude at which they are located, and the shocks that have affected the different observation units at the same time in a given year (e.g. the financial economic crisis of 2009 or the serious droughts that have affected the entire Alpine range).

Our results indicate that, on average over the period considered, one metre less snow falling during the season is associated with a 1.3 per cent decrease in passes for the ski resorts, under the same conditions. Projections for 2100 predict that the decline in snowfall in winter is between 30 and 45 per cent (EURO-CORDEX, 2014), due to lower snow frequency and intensity. According to our estimates, a 40 per cent reduction in the amount of snow in a season would mean a 7 per cent decrease in ski passes on average, which could be far more severe in locations that are at lower altitudes. Artificial snow is not in itself capable of supporting the tourist demand linked to winter sports. The results are confirmed by analysing the relationship between climate variables and monthly overnight stays in accommodation facilities, although in this case the relationship with snow precipitation is less strong. At the same time, Alpine resorts with the same climate conditions but with a wider and more varied set of accommodation and culture on offer host a greater number of visitors, appearing more able to attract non-skiers.

With this work, we have provided initial granular evidence of the relationship between tourist flows and climate change, understood as variations in snowfall. Our estimates show that the impacts could be substantial, especially for low-altitude locations. As already mentioned by the Ministers of the member countries at the end of the 2006 Alpine Conference, it is necessary to carefully evaluate an adaptation strategy that does not only include artificial snowmaking, which is particularly costly and energy-intensive. On the other hand, a wider and more diverse receptive cultural offer seems to be able to increase tourist numbers. It seems crucial, therefore, to expand the tourism offer with activities not strictly related to snow and invest in infrastructure and programmes able to support and push other types of tourism, such as those relating to congresses, wellness centers or winter sports not dependent on the presence of snow.

Our research would benefit from the extension of the dataset both geographically and temporally, so as to strengthen our estimates and also to capture longer-term relationships. A further point of analysis could be given by the replacement effects during the year, as mountain summer tourism is often referred to as a potential beneficiary of global warming, which would instead make bathing areas in the Mediterranean more inhospitable: the empirical evidence in this regard is still limited and is not unambiguous, since even the summer mountain ecosystem could be affected by changing climate conditions.

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7. DOES THE HEAT 'COOL' THE MARKETS? CLIMATE CHANGE AND BUYING HOUSES

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Classification of JEL: C78, G1, Q54, R21, R31

Keywords: search for homes, temperatures, climate change, online search.

Introduction. — The body of literature on the impacts of climate change on the economy has grown significantly in recent years. (see Dell *et al.*, 2014 and Carleton and Hsiang, 2016 for a review). In particular, recent studies have found that, even in advanced economies, the value added in a wide range of production sectors, including real estate, has been negatively impacted by unfavourable temperatures in recent decades. (Colacito *et al.*, 2019).

However, studies on the effects of climate change on the real estate sector, which accounts for the majority of household wealth in many nations, have primarily focused on the risk of sea level rise, a material threat to real estate properties located near the coasts. On the other hand, there is currently little evidence of how temperature affects real estate prices. The few studies that have been conducted, beginning with Roback (1982), have mostly examined the long-term correlation between urban growth (and the implications for house prices) and the presence of 'climate amenities' such as mild temperatures (Blomquist *et al.*, 1988; Kahn, 2009; Bunten and Kahn, 2014; Albouy *et al.*, 2016; Galinato and Tantihkarnchana, 2018). Neverthless, temperatures can also affect house prices through other unexplored channels, such as their impact on the housing search process.

Heat and selling prices. — Some evidence concerning the Italian real estate market suggests that extremely hot temperatures have a negative effect on house prices even in the short term. A regression analysis on data from the Real Estate Market Observatory (OMI) for Italian provincial capitals over the years 2009-2019 shows that an increase in days with average temperatures above 25°C in a year means a reduction in selling prices of residential properties in the following year. In our recent work (Cascarano and Natoli, 2022), we start with this evidence to look into a possible mechanism relating to the effect of high temperatures on property search processes. Heatwaves are known to harm human health and reduce individual productivity, both at work and during outdoor leisure activities; it is also well documented that, as a result of intense weather phenomena, awareness of future risks associated with climate change increases significantly (Choi *et al*. 2020, among others). As a result, extreme heat, a direct manifestation of climate change, may have a negative impact on the house search process, increasing average real estate search costs and the likelihood of agreement between buyers and sellers, as well as tilting buyers' preferences towards homes that offer stronger protection (also in terms of air conditioning expenditures) against recurring heat waves.

Effects on search processes and house sales. — To explore the connection between high temperatures and house searches, the work uses different data sources with the aim of documenting the impact at different stages of the search process: since this process can be partly carried out on the web, we use information relating to both online and physical searches. As regards online searches, we use data obtained from about 10 million listings of houses for sale published on the main real estate services platform in Italy (Immobiliare.it);

* Bank of Italy.

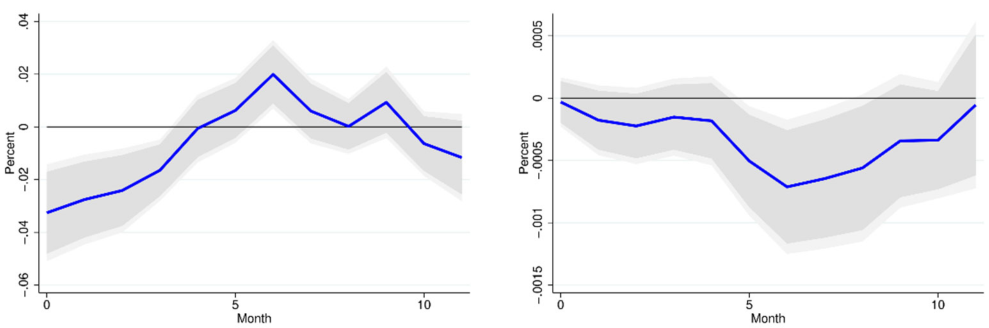
as regards physical research, we take into account appointments made by buyers and sellers with real estate agents (Tecnocasa) as well as the number of sales made in various cities (data provided by National Council of Notaries). The analysis is carried out for the Italian provincial capitals on a monthly basis from 2016 to 2019.

Econometric analyses of these data show that an increase in the monthly incidence of days with average temperature above 25°C reduces housing searches, both online and physical, and lengthens the time to sale of real estate. In terms of online searches, this is reflected in a significant decrease in the number of views (clicks) and online contact requests per single ad. This effect is visible in panel (a) of the figure, showing the impact on requests, over a 12-month horizon, of an increase in the number of excessively hot days within one month. Added to this we find a decrease in physical appointments recorded by real estate agencies with buyers and sellers, implying a decrease in both the market's tightness (as determined by the ratio between buyers and sellers) and its overall thickness (sum of buyers and sellers). It should be noted that, according to a robustness analysis, the negative impact of temperatures on online research and appointments can only be seen when temperatures are extremely high. This result adds an important element to the literature documenting the nonlinear effects of temperatures on human health (Barreca et al., 2016), extending the previous result to search processes that are potentially exposed to severe temperatures.

The effects of high temperatures on housing research have implications for the dynamics of local housing markets: a decrease in demand and appointments is accompanied, with a delay of a few months, by a reduction in transactions.

Figure 7.1 Elasticity of online demand and posted prices at high temperatures

(a) Contact requests *(B) Posted prices*



Note: The two panels show the impulse response functions estimated according to Jordà's Local Projections (LP) approach (2005). For each month following the temperature shock, the blue line represents the elasticity resulting from the estimate of the LP model. The dependent variable is the logarithm of visits (panel (a) or the posted price (panel (b). The dark gray area represents the 90 per cent confidence band, the light gray one at 95 per cent.

Sources: Immobiliare.it, and JRC MARS Meteorological Database

Effects on posted prices. — The sellers' prices are affected by the downturn in market activity; after exceptionally hot months, individual ad prices fall significantly (see panel (b) of the figure). It is possible to quantify the effects on home searches and sales as follows: if the number of extremely hot days increases by just one day a month, both buyer and seller appointments are reduced by around 2 per cent. If this increase in hot days spreads out to all months of the year, it would result in an annual fall in posted prices of about 4 per cent, producing a direct impact on sale prices.

Differentiated impacts: climate-resilient housing and houses for rent. Different types of properties within cities are affected differently by high temperatures. In particular, the decline in demand is less pronounced for homes that offer some protection from hot temperatures (those having open spaces or higher energy efficiency). This is consistent with an increase in the focus on climate concerns during periods of excessive heat, which would drive up demand for climate-safe housing. These heterogeneities may explain the more persistent effect found on ask prices: while housing searches may resume in aggregate after the extreme heat episode has passed, this may not occur for the segment of buildings that are less resilient to climate risks, the demand for which would decline persistently in favour of dwellings that are more adaptable to hot climates.

Aside from differences based on property type, the effects seem to be weaker in the case of rental ads rather than sales ads. This evidence could simply be related to the fact that renting is a more urgent (and thus less easy to postpone) necessity; however, it may also depend on the fact that, unlike purchasing, renting does not involve a long-term commitment; it is therefore a less risky activity and, as a result, is less sensitive to climate risks.

Conclusions. Overall, our findings indicate that climate change has the potential to influence the real estate market directly through the effects of high temperatures on real estate searches, and that both supply and demand are developing adaptation strategies for increasingly hot temperatures. More broadly, the analysis demonstrates an effect of meteorological variations on human activity that extends beyond the direct effect on human health and could apply to any type of active search conducted outdoors or in non-air-conditioned locations (e.g. job searches in certain production sectors).

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8. TEMPERATURES AND ECONOMIC ACTIVITY: BETWEEN PAST AND FUTURE

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Classification of JEL: N00, O44 Q54

Keywords: climate change, economic growth, long-run.

Introduction. — Effective responses to climate change require estimates of aggregate economic effects. For this reason, there has been a significant increase in studies on the relationship between climate and the economy in recent years, with the aim of measuring the potential economic consequences of climate change and understanding its mechanisms.[1] In our work (Brunetti *et al.*, 2022), we propose a long-term assessment of the effects of the increase in temperatures on Italian GDP per capita.[2] In particular, the study reconstructs the trends in temperatures at provincial level in Italy since the end of the nineteenth century and estimates its effects on the economy, also drawing up possible future scenarios.

Cross-country studies. — At international level, a great deal of evidence has been produced showing that rising temperatures affect economic activity negatively through a wide range of channels such as the contraction of agricultural production, the reduction of workers' productivity, and the fall in investment in some sectors that are more sensitive to the consequences of global warming. The effects are most often nonlinear and heterogeneous in time and space (Burke, Hsiang and Miguel, 2015). Simulations suggest that the expected temperature increase by 2100 may result in a non-negligible product loss: the estimates indicate reductions in global production that vary, depending on the climate scenarios considered, between 2 and 14 per cent at the end of the century (see for example Acevedo *et al.*, 2018; Kalkuhl and Wenz, 2020; Newell, Prest and Sexton, 2021).

Studies on Italy. — For Italy, several assessments were carried out (mainly in cross-country analyses) of the aggregate economic effects. In particular, Carraro, Crimi and Sgobbi (2008) examine a scenario in which temperatures increase by + 1 °C at the end of the century with respect to 2001: in this case, Italian GDP by 2050 would be between 0.12 and 0.2 per cent lower than the level that would be expected in the absence of temperature increases. However, impacts and costs would increase exponentially in the second half of the century. In an international report, McCallum *et al.* (2013) examine more extreme climate change scenarios with temperature increases of up to + 3.7 °C in 2100, which would produce a 2 per cent reduction in GDP in Italy by 2050.

With reference to GDP per capita, in a scenario with temperatures increasing by up to +4 °C at the end of the century (with respect to the average 1850-1900 level), Ronchi (2019) makes projections of production losses for Italy that cumulate, ending in a GDP per capita that is lower by 3.7 per cent in 2050 and 8.5 per cent in 2080 compared with the level that would be recorded without temperature increases. Kahn *et al.* (2021) examine 174 countries over

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[1] Among the many references, see: Dell, Jones and Olken (2012 and 2014); Kahn *et al.* (2021).

[2] The study does not *directly* measure the impacts of specific events caused by rising temperatures (e.g. natural disasters, deterioration of health, increased mortality, migration, etc.), and in focusing substantially on GDP as an interest variable it does not directly measure 'stock' losses (damage to buildings, land and infrastructure: see Ronchi, 2019, p. 27). Nevertheless, these events are indirectly taken into account when examining the effects of temperature increases on GDP per capita growth.

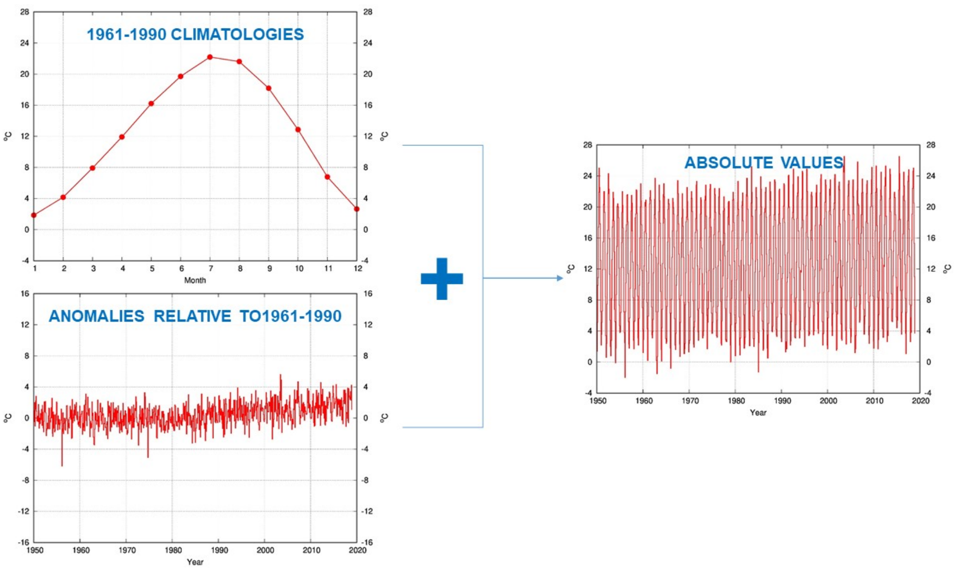
the period 1960-2014 and estimate a possible reduction in GDP per capita for Italy of up to 7 per cent in 2100. Finally, Olper *et al*. (2021) use data at provincial level from 1980 to 2014 and, in a scenario without mitigation or adaptation, they estimate per capita GDP reduction at 2100, mainly for the Mezzogiorno (-4.0 per cent) and a severe reduction in productivity in the agricultural sector (-35 per cent).

The reconstruction of temperature data. — A central point of our analysis is the reconstruction of temperature data for the entire national territory at provincial level since the end of the nineteenth century. This operation presents at least three critical issues. First, the temperature values recorded by weather stations in Italy for a long period are only available for a few geographical points. Second, the number of stations is not constant over time: new activations or decommissions of stations complicate the reconstruction. Finally, the temperature values recorded by the stations often lack homogeneity, which is defined as the ability to detect temperature dynamics only attributable to weather variations, and therefore purified by the disturbances relating to the station's history, such as changing instruments, the improvement of shields from solar radiation, and the displacement of the instruments or of the station itself to another place.

To overcome these problems, we have adopted a method of reconstruction called the anomalies method,[3] which is divided into three stages (Figure 8.1): in the first, an average monthly temperature value is calculated for every point in the territory on the basis of a dataset for a set of weather stations; in the second stage, using a different set of stations, annual deviations from this average value are estimated. From the combination of these values (third stage) we obtain the historical series of the average temperatures for territory cells of about 800mt x 800mt (more than 400,000 points) for the last 150 years; these series are subsequently aggregated at provincial level.

Figure 8.1 Temperature series reconstruction diagram

(anomalies method)



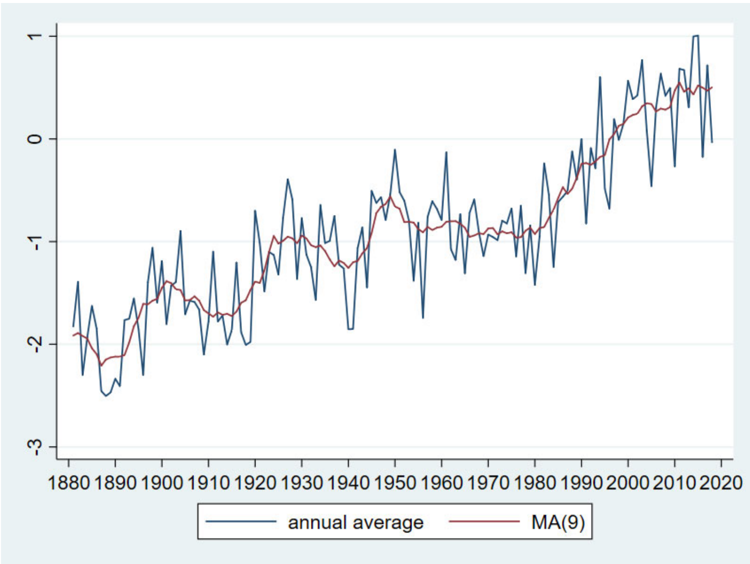
Source: Brunetti *et al*. (2006).

[3] In summary, a monthly time series for a meteorological variable is expressed by the sum of: a) an average seasonal cycle (climatology) that can be assumed as being constant over time; b) the deviation from the cycle, which is time-varying (anomaly). The anomalies method consists in the independent reconstruction (that is, with two different datasets), on the one hand of the climatology for a given reference period, and on the other hand of the anomalies (Brunetti et al., 2006).

Figure 8.2 shows the evolution of the average temperature from the end of the 19th century to the present day. Based on this reconstruction, the temperature in Italy increased by about 2 °C between the end of the nineteenth and the beginning of the twenty-first century. The evolution was uniform between provinces, with a slightly different trend between North (higher) and South.[4]

Figure 8.2 Evolution of average temperature between 1880 and 2020

(compared with the 1990-2000 average)



Source: Our reconstruction.

The long term. — The analysis proposed in this work is characterized by the measurement of the impacts of global warming over a long-run/term horizon using variations in the ten-year averages of the data. With this approach, the effects of temperature increases may be different from those examined over short periods, with a meteorological variability prevailing in the latter that is not attributable to persistent climate change. In addition, long-term analysis performed on the past can incorporate adaptation or intensification processes and produce results that are more suitable to being projected into the future over a long-term time horizon. Adaptation can result from the process of development that has translated (and will result) into the adoption of technological innovations, as well as in the change of production specialization towards activities with a different sensitivity to global warming. Nonlinearity in the relationship between temperatures and economic activity produce intensification: if a certain temperature threshold is exceeded, the negative effects of global warming can be more intense.

Results. — The relationship between average temperatures and GDP per capita levels in Italy over the entire historical period examined is nonlinear with an inverted-U shape, and has a point of inversion at about 15 °C, beyond which the relationship becomes negative. The long-term impacts of the temperature levels on GDP per capita growth are significant and negative. On the basis of the estimated coefficients, the future dynamics of the GDP per capita which could prevail considering possible further increases in temperatures up to the

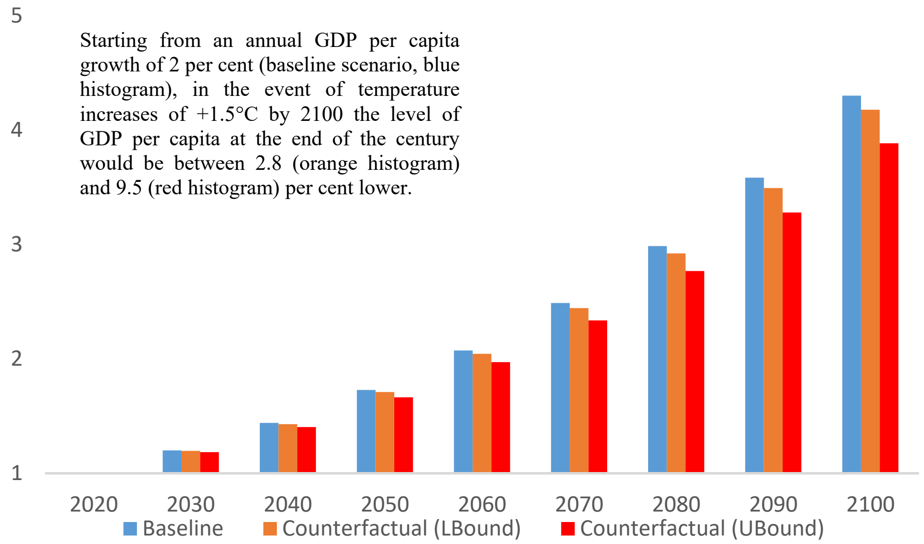
[4] The reasons for this slight difference in temperature trends along the north-south axis of the country are the subject of study among climatologists, who have put forward the hypothesis that it mainly depends on the greater exposure of the South to desert dusts that create a 'dimming' effect that limits solar radiation on the Earth's surface. See Brunetti *et al.* (2016).

end of the century was computed. Starting from a hypothetical baseline scenario of economic growth of 2 per cent per year at stable temperatures for the next eighty years (which essentially reproduces the historical trend), it has been calculated that if the sensitivity of GDP per capita to the increase in temperatures stood at the average levels estimated for the twentieth century, an increase of 1.5 °C, consistent for Italy with an intermediate scenario for future emissions,[5] could lead to a level of GDP per capita between 2.8 and 9.5 per cent lower in 2100 than the baseline scenario (Figure 8.3). This implies a reduction in the annual growth rate from 2 per cent in the baseline scenario to rates between 1.97 and 1.85 per cent.

Finally, in addition to average temperatures, the impact of the higher frequency of high temperatures was also examined. We found, particularly for the last two decades of the twentieth century, when the frequency of high daily temperatures (above 28 °C) began to increase significantly, that these higher frequencies have negatively affected value added and productivity, especially in the sectors of agriculture and industry (Figure 8.4).

Figure 8.3 The impact of temperature increases on long-term GDP dynamics, 2020-2100

(GDP per capita 2020=1)

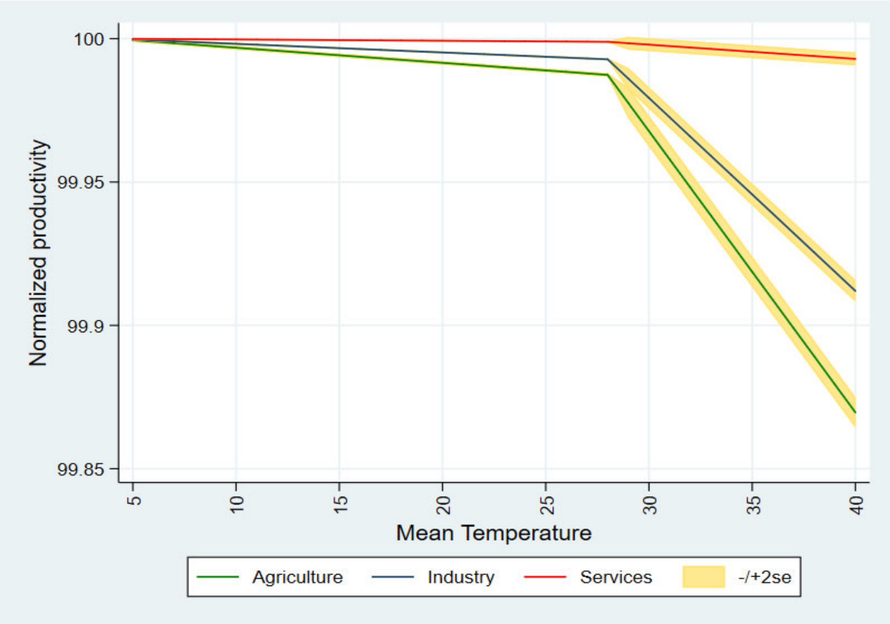


Note: The histograms show the evolution of GDP per capita levels in the baseline scenario at constant temperatures (blue histogram) and in the event of a gradual increase in temperatures of +1.5 °C by 2100 (orange and red histograms). The path traced by the orange histogram is obtained using the lowest coefficient among those estimated (*LBound*: = -0.029), while the red histogram uses the highest coefficient (*UBound* = -0.101).

Source: Our calculations.

[5] The main international forecasts formulate different assumptions of global temperature growth based on the concentration of greenhouse gases in the atmosphere. The scenarios refer to temperature deviations from the global average prevailing in the period 1850-1900 (for Italy, the increases in temperature recorded to date are 1°C higher than the average at global level). The assumption of a temperature increase of one and a half degrees by 2100 compared with 2020 is consistent with an SSP2-4.5 intermediate emissions scenario. Intergovernmental Panel on Climate Change (2021).

Figure 8.4 The impact of increases in the daily frequency of high temperatures (> 28°C) on the productivity of macro sectors, 1981-2001
(compared with the 1990-2000 average)



Note: Graphical representation of piecewise linear estimation coefficients between temperature and productivity.

Source: Our calculations.

Conclusions. — The reconstruction of the temperatures recorded in Italy since the end of the nineteenth century has allowed us to investigate the relationship between global warming and economic activity over a long time span, and to perform econometric estimates using data with a ten-year frequency. This approach is useful as it allows us to overcome (at least partially) the problem arising from using data with an annual frequency that most often capture non-persistent, meteorological weather oscillations, not necessarily linked to climate change. The relationship between temperature levels and GDP per capita levels emerges as nonlinear, with negative effects beyond a certain threshold. The effects on GDP per capita growth are negative and significant too. Projecting into the future the long-term impacts estimated for the past, we have computed the economic effects that could derive from temperature increases of about + 1.5 °C by 2100. Based on a benchmark scenario of GDP per capita growth at 2 per cent with stable temperatures, the coefficients obtained from our estimates imply that the expected temperature increases could reduce the level of GDP per capita by between 2.8 and 9.5 per cent at the end of the century (compared with what would prevail with stable temperatures). These assessments, which necessarily have a high degree of uncertainty due to the nature of the exercise carried out, are consistent with those of other cross-country studies.

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9. WHEN IT'S TOO HOT, STUDENTS' PERFORMANCE IS NOT THE ONLY THING THAT IS AFFECTED

Rosario Maria Ballatore,[1] Alessandro Palma[2] and Daniela Vuri[3]

Classification of JEL: J21, J24, Q54, O15

Keywords: student performance, cognitive skills, emotional stress, temperatures, climate change.

Introduction. Recent studies by the Intergovernmental Panel on Climate Change (IPCC) suggest a 1.5 °C increase in global temperatures between 2030 and 2050. This variation, which may appear small, masks a wide geographical heterogeneity, with some areas of the planet experiencing much higher increases than the global average. Not only: as recently documented by the World Meteorological Organization's latest report, the frequency, duration and intensity of heatwaves and other extreme climate events have increased dramatically over the past 15 years (Zhongming *et al.*, 2021). In 2021, during the exceptional heat that occurred in the second week of August in Europe, a weather station in Southern Italy reached recorded a temperature of 48.8 °C, setting a new record for the continent.

Starting from this evidence, one strand of economic literature analyses the potentially negative effects of extreme temperature peaks. One of the fields mainly investigated related to the effects on educational processes (Griff Zivin *et al.*, 2018). In our paper (Ballatore *et al*., 2022), we study the short-term impacts on cognitive performance, investigating the effect of temperatures on students' results in standardized tests of Italian and mathematics carried out in Italy between 2012 and 2017.

The study of the effect of thermal shocks on student performance is important for several reasons. First, cognitive performance is crucial for many important steps in our lives. Evidence of its partial reduction when temperatures are high could have potentially significant implications when it comes to planning cognitively costly activities (such as public selection exams or university admission tests). On the other hand, given that the results of school assessments are often used to provide comparisons between different geographical areas within countries (as is the case in Italy) it should be taken into account that exposure to thermal stress during the tests is not the same for students in different territories. Finally, consistently high temperatures could produce not only transient effects but also more lasting negative impacts, for example by reducing students' learning, with potential long-term repercussions on employment probabilities, wages or the risk of ending up in poverty (Deschênes, 2014).

Temperature variations between tests as a natural experiment. — The INVALSI data gives us the opportunity to study the link between temperature and student performance. Through standardized tests, the National Assessment System (SNV) evaluates the Italian and mathematical skills of students in primary schools (in grades 2 and 5), in those of lower secondary (in grade 8) and for students of upper secondary (grade 10). The tests are scheduled between the first half of May and the first weeks[4] of June, when outdoor temperatures are rising and the first heat waves begin to occur. We use information on the

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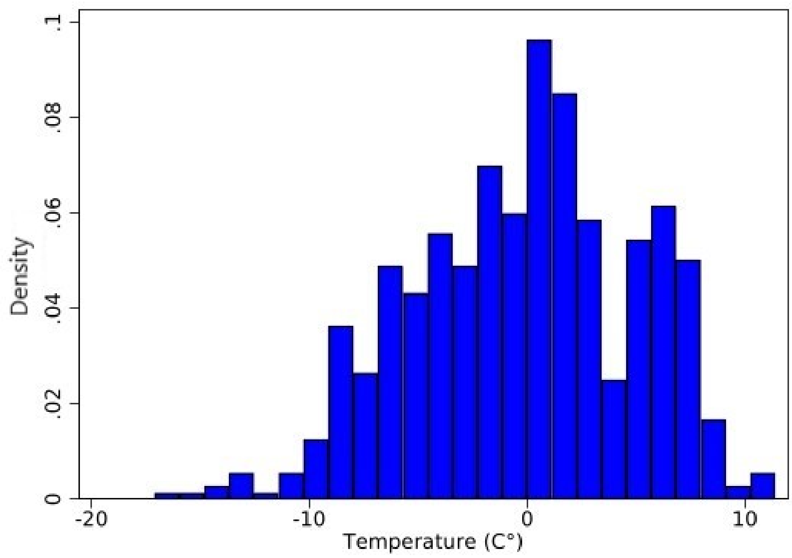
[4] The tests are held in May for students in grades 2, 5 and 10 and in June for those in grade 8.

geographical location of schools to match our student data with the climate conditions at municipal level on test days using information from Agri-4-Cast, which contains daily data on minimum, maximum and average temperatures, as well as on precipitation and wind speeds.

The empirical strategy we use to identify the causal effect of temperature on student performance is very simple. Our analysis is based on the variation in temperatures observed for each student during the test days in different years. What makes this context a natural and therefore optimal experiment for the identification of the causal effect is the fact that the evaluation days are the same for the whole national territory and cannot be changed by school or region. In addition, the dates of the tests are set at the beginning of each year, making it impossible to predict — at the time of programming — the climate conditions on the day of the test. Figure 1 shows the ranges of temperature changes, showing a variation interval of ± 10 °C between test days in different years.

Figure 9.1 Distribution of temperature shocks over different test days



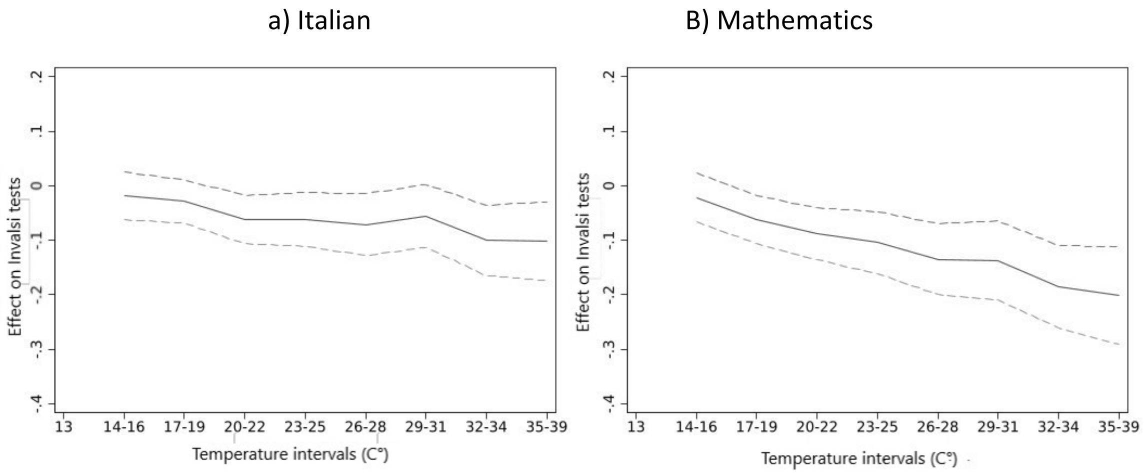
Note: Pooling of school years. Absolute temperature variations (in degrees C) between the days when the tests are carried out.

Source: Our calculations based on Agri4Cast data.

The results we have obtained confirm what emerges in the literature. Estimates[5] indicate that higher temperatures on test days significantly reduce student performance. The effects are small and differentiated by subject, with those for the mathematics test being twice those for Italian. This difference has already been highlighted in the literature and is also confirmed in neuroscience studies that indicate that the most temperature sensitive part of the human brain is that generally dedicated to the resolution of logical operations. Although the overall effects may appear small in comparison with those of other inputs from the learning process (such as having one or both parents with a high education levels), it is possible that the impacts of temperatures are nonlinear, i.e. they vary as the temperature increases. Figure 2 shows exactly that. Both in Italian (panel a) and in mathematics (panel b), the effects of temperature are stronger when extreme peaks occur.

[5] Estimates are made by including individual fixed effects.

Figure 9.2 Nonlinear effects of temperatures on the results of Italian and mathematics tests



Note: Pooling of school years and degrees. Effects expressed in terms of standard deviation. The effects are expressed with respect to temperatures less than or equal to 13°C.

Source: Our calculations based on Invalsi and Agri4Cast data.

To be sure of our results, we have conducted a series of robustness checks. For example, we tried to use the temperatures detected several days before or after the date of the tests to rule out that our results were driven by an underlying process that could correlate temperatures and performance. If the effect we estimate is that which results from a deterioration in performance due to high temperatures on the day of the tests, we should not observe significant effects when using the temperatures of days other than those of the tests, especially in subsequent ones. The evidence we report goes exactly in this direction, as we find zero effects of temperatures on other days.

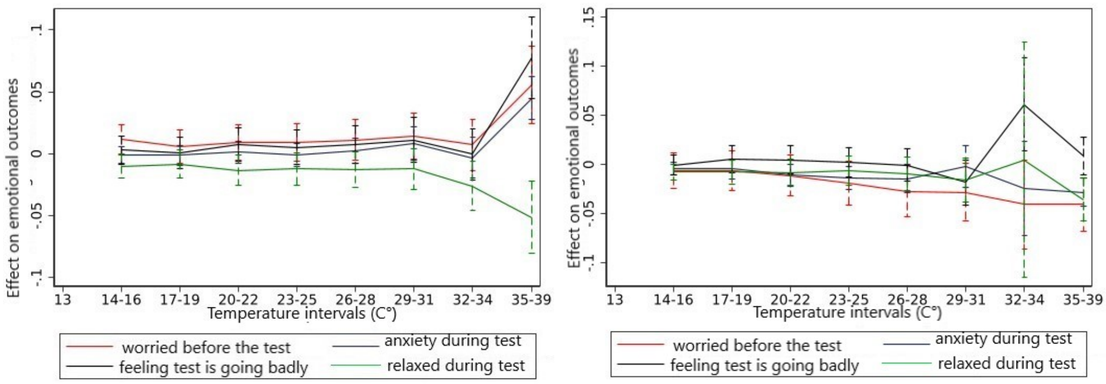
One aspect not addressed in the literature is that of potentially different impacts for different age groups, in line with the fact that the medical literature provides evidence that the human body's thermoregulation system improves with growth and development (Van Someren, 2007). Investigating these heterogeneities is very important for policy implications, making it possible to better identify the negative effects of extreme temperatures and to programme interventions to counter them more precisely. Covering very different ages, the data at our disposal allow us to distinguish the effects of temperature by an age range ranging from 7 years in grade 2 of primary school to 15 years for students in upper secondary school. For both mathematics and Italian, we only observe a negative and significant effect of high temperature levels on the test score for students aged 7 and 10 years (grades 2 and 5). In particular, for these age groups, the effects on the Italian test become significant at temperatures above 34 °C, while for that of mathematics, the effects occur from 31 °C upwards. On the contrary, they are not different from zero for grades 8 and 10 in both cognitive domains. Overall, this set of results shows that students in early adolescence (ages 13-15) are much less sensitive to thermal stress than pre-teens (ages 7-10).

Effects not only on performance. — It is possible that the temperature acts on other aspects besides cognitive performance. For example, particularly high temperatures could increase emotional stress and perception of fatigue, which often prove decisive during evaluation tests. To assess this problem, we use the questionnaire only given at the end of the evaluation session to students in grades 5 and 10, which collects additional information on students' perceptions during the tests. In particular, the data at our disposal allow us to verify the presence of temperature effects on four emotional aspects: i) being concerned before the test; ii) the feeling that the test is not going well; iii) experiencing anxiety during the tests; and

iv) feeling relaxed during the test. Panels (a) and (b) in Figure 9.3 show the estimates for each of the four variables, distinguishing by temperature ranges (as in Figure 2). The message that emerges is clear: at extreme temperatures, i.e. above 35 °C, emotional stress increases for younger students (those in grade 5) but not for those in grade 10. Although these results should be interpreted with caution, in the absence of a theoretical model that highlights the mechanisms that determine them, this evidence is also interesting in light of the heterogeneity of the effects on performance on different student age group: the students for whom we observe a greater loss of performance are in fact also those who experience a sharper emotional deterioration.

Figure 9.3 Nonlinear effects of temperatures on some emotional outcomes

a) Grade 5 B) Grade 10



Note: Effects are expressed in percentage points and measure the increase (decrease) of the probability that the student will perceive a certain emotion during or before the tests. The effects are expressed with respect to temperatures less than or equal to 13 °C.

Source: Our calculations based on Invalsi and Agri4Cast data.

What to do then? — In this work, we used the census data on student scores in standardized Italian and mathematics tests together with information on temperatures detected at municipal level on test days to identify the effect of temperature on cognitive performance. The empirical evidence indicates negative effects especially in mathematics, at extreme temperatures and for smaller students. There are also signs of increased emotional stress during the assessment for younger students, such as increased anxiety and a feeling of worsening well-being during tests. Our analysis has several policy implications. First, our results could help public decision-makers to design effective strategies to counter the effects of extreme heat on student performance, for example by improving the quality of school infrastructures with particular emphasis on the provision of air conditioning systems that are currently scarce in Italian schools.[6] Second, evidence of performance deterioration at high temperatures suggests that better scheduling of evaluative activities in schools (and not only) is possible. One example could be to anticipate the date of the tests or to provide different dates for different areas of the country in order to make the test conditions between the regions more uniform.

[6] Data collected by the Ministry of Education and Research (MIUR) in 2021 show that less than 2 per cent of school buildings in Italy have air conditioning.

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10. ACCIDENTS AT WORK AND POLLUTION

Domenico Depalo* and Alessandro Palma**

Classification of JEL: I18, J28, J81, Q51, Q53

Keywords: air pollution, safety at work, accidents at work, instrumental variables, winter heating.

Introduction. According to the International Labour Organization, about 320 million non-fatal injuries at work occur every year in the world and two million workers lose their lives. These accidents lead to loss of human capital and work skills, with serious economic and social repercussions (Pouliakas and Theodossiou, 2013). Given the significance of accidents at work, a great deal of extensive literature has analysed the causes. Although the role of production processes and regulation has been widely demonstrated, the role played by pollution is much less well-known. In our work (Depalo and Palma, 2022), we focus on the effects of overall air quality on work-related accidents in Italy, where the limits set by EU regulations are often exceeded.

The literature on the long-term effects of pollution on mortality and morbidity is well established. More recent evidence has shown that air pollution also has immediate effects, for example on labour supply (Hanna and Oliva, 2015) and productivity (Graff Zivin and Neidell, 2012; Chang *et al.*, 2016; He *et al.*, 2018; Was *et al.*, 2021).

Our analysis is the first to investigate the causal effects of air pollution on accidents at work, rather than just the correlation between the two variables. We focus on injuries, disabilities and deaths of workers in Italy between 2014 and 2018.

This estimate presents two main challenges, which — if not properly considered — can lead to wrong conclusions: 1) air quality depends largely on the level of economic activity, which in turn increases the likelihood of suffering from an accident at work (endogeneity); and 2) the strategic behaviour of workers, who may decide to work in places with better air quality or to avoid periods when pollution levels are highest.

To address these issues, we implement an instrumental variables estimator, exploiting the heating rules. The identification of the causal effect of pollution on accidents is possible thanks to the fact that the preset rules for winter heating, which create an increase in polluting emissions, only affect the supply of work through air quality.

Data. — A distinctive element of the analysis is the unique database that we use. The database merges different sources of an administrative nature, all at municipal level and at a daily frequency: INAIL (National Injury Insurance Institute) for accidents, AirBase for the concentration of different pollutants, and INPS-UNIEMENS (National Social Security Institute), at a monthly frequency, for the composition of the workforce; the dates of the heating are regulated by law (Presidential Decrees 412/1993 and 74/2013).

The outcome of interest is accidents at work. The legislator defines accidents at work as traumatic events that cause an injury. An accident may result in temporary work disability (at least three working days lost), permanent disability (total or partial), or death. With very few exceptions (e.g. the police forces), all Italian workers must be insured against accidents at work through INAIL. Mandatory registration with INAIL ensures that all accidents are recorded; in addition, the registration of an accident takes place regardless of how the

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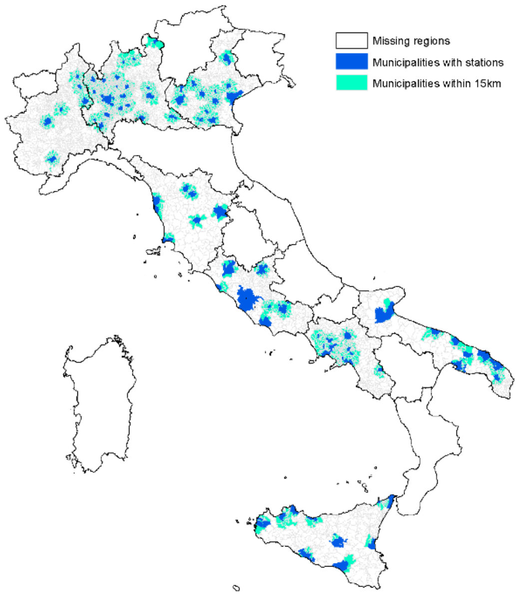
information is collected (for example, through the employer or through the hospital). These characteristics guarantee full coverage of the phenomenon, as is also recognized by Eurostat. For this analysis, we reached an agreement with INAIL to obtain municipal data from 2014 to 2018 from eight Italian regions (5,201 municipalities): Lombardy, Veneto and Piedmont (North), Tuscany and Lazio (Centro), and Campania, Puglia and Sicily (South). The initial sample consists of more than 2.1 million events (approximately 421,000 each year) and covers about 83 per cent of the total number of accidents at work in Italy during the period considered.

Air pollution data comes from the European AirBase database, which collects information on the hourly concentrations of pollutants recorded by monitoring stations. The pollutants considered in the analysis are PM10, CO, NO_2 and SO_2. The number of monitoring stations for these elements may vary in space and time. In Figure 10.1, we show the map with the municipalities in which there is at least one control unit and therefore that can be used for analysis. Starting from the data collected by the control units, we build an Air Quality Index (AQI) following the indications provided by the European Environmental Agency, an agency of the European Commission.

Figure 10.1 The distribution of control units in the municipalities of the regions concerned



Source: Calculations based on AirBase data.

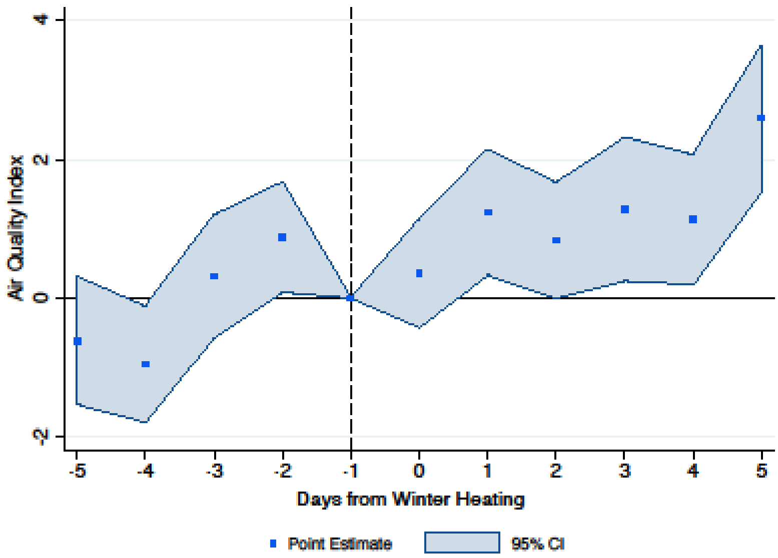
We also use INPS data to consider the composition of the workforce at municipal level and on a monthly basis. For each worker, we look at their demographic characteristics (age, gender), the duration and type of contract (full-time, part-time, fixed time, indefinite time), the level (workers, employees, managers, apprentices) and the economic sector (ATECO code).

Finally, we use data on general strikes and the public transport sector at national level, as well as on major national holidays.

Methodology. — To estimate how air quality causes accidents in the labour market, we use a linear regression model, which takes into account the individual characteristics of the persons involved, those of companies, weather conditions, seasonality, strike days and national holidays. In addition, to limit the effects of omitted variables, we take into account the non-measurable heterogeneity, at the level of the municipality, the month and the day of the week.

The estimation method is the instrumental variables estimator, which uses the dates during which heating can be switched on to remove endogenity (Fan *et al.*, 2020). These dates are differentiated by geographical area (6 climate zones), are established by law, and cannot be manipulated by workers or employers. Switching on the heating significantly worsens air quality (Figure 10.2 documents what happens in the days following the start of heating), but has no effect on labour supply. This is an essential requirement for the method of instrumental variables to be able to identify the causal effect of pollution on accidents. This property makes the link between air quality and the effect on economic activity 'unidirectional', thereby allowing us to evaluate how the first causes the second, but not vice versa. The simple correlation between the two variables would identify a 'bi-directional' link between the variables of interest.

Figure 10.2 Switching on heating causes a deterioration in air quality



Source: Authors' calculations.

Results. — According to our estimates, accidents at work increase by 14 per cent with an increase in the AQI by one standard deviation (SD),[7] equal to 2 per cent more accidents with a 10 per cent increase in the AQI. However, we do not observe significant effects on disability and mortality. Based on these findings, air pollution does not have a significant impact on the most serious accidents, but it does involve a large number of workers.

To explore the heterogeneity of effects, we also divided the sample by economic sector, distinguishing between outdoor and indoor sectors: in the first case, the estimated elasticity implies that an increase in the AQI of one SD causes at least 11 per cent more injuries; in the second case, the increase would be of at least 4 per cent. The estimated effect is therefore

[7]A standard deviation in the AQI is, indicatively, the difference between a heavily urbanized area and a rural one.

greater for workers who spend most of their time outdoors, as is also suggested by simple correlations (Schifano *et al.*, 2019).

These results can be explained by different mechanisms. An increasing number of epidemiological and economic studies show that short-term exposure to a high concentration of pollution, particularly CO and PM10, not only increases the risk of cardiovascular and lung disease, but also has a significant impact on brain activity, altering concentration and mental readiness (Kleinman and Campbell, 2014). At work, these pathoological mechanisms can lead to memory disorders, fatigue, loss of concentration, and attention deficits. These assumptions are in line with the latest empirical work using counterfactual methods, which find that pollution has negative effects on productivity (Graff Zivin and Neidell 2012; Chang *et al*., 2016), on cognitive skills and education outcomes (Ebenstein *et al.,* 2016), on quality of work (Heyes *et al.* 2016; Huang *et al*., 2020), and on the number of road accidents (Sager, 2019).

All of these studies provide compelling arguments to validate our initial hypothesis: air pollution alters cognitive abilities, increases fatigue and reduces mental readiness, causing more accidents at work.

Implications. — In Italy, as in many other countries, companies bear the full costs of compensation (relating to the salary paid) for less serious accidents, i.e. those with sick leave of less than four days, while the costs of the most serious accidents are compensated by a national insurance payment (from INAIL in the Italian case) and are borne by the community. To what extent are the costs of pollution-related accidents distributed between private companies and national insurance? To answer this question, we distinguish the sample according to the days of sick leave. Our results suggest that the effects of pollution are concentrated on the least serious accidents (with less than four days of sick leave), the compensation costs of which are entirely borne by private companies (regardless of whether they are directly responsible for the pollution). To a lesser extent, air pollution also causes more serious accidents that result in longer sickness-related absences and, most likely, higher costs entirely borne by INAIL; in this case, however, companies face the indirect cost of a reduction in the workforce but do not make any monetary disbursement to compensate injured workers.

It follows that, in addition to the public operator, private companies (including those that do not pollute) also have an incentive to invest in safety linked to the reduction of exposure to air pollutants that are responsible for poor air quality, in particular finer pollutants such as PM10.

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11. FROM GRANDFATHERING TO AUCTIONS: IMPACT OF THE EU ETS ON THE FOREIGN TRADE OF ITALIAN COMPANIES

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Classification of JEL: Q54, F14, F18

Keywords: EU ETS, climate change, international trade, greenhouse gases, carbon leakage.

Introduction. The European Union (EU) has committed to achieving very ambitious targets for climate change mitigation, aiming to achieve complete decarbonization by 2050. Mitigation policies, which aim to reduce greenhouse gas emissions from human sources, inevitably tend to make the use of fossil fuels more burdensome: it is therefore crucial to assess the extent of the impact of these policies on both households and businesses; the analysis presented in this work focuses on the latter.

The EU strategy. — The EU's main policy tool for achieving this objective is the EU Emission Trading System *(*EU ETS). It covers a total of about 11,000 industrial plants (of which around 1,000 in Italy) which account for almost 40 per cent of the EU's greenhouse gas emissions. This instrument has been in force since 2005 and is based on a cap and trade scheme for the most polluting industrial plants. Once the annual ceiling on emissions authorized at the Community level has been set and the European Union Allowances (EUAs) have been allocated, plants may purchase or sell allowances at the current price and, at the end of each year, must offset their actual verified emissions with the same quantity of allowances.

In the first and second phases of the EU ETS (Figure 11.1), between 2005-2007 and 2008-2012, the EUAs were allocated free of charge to each installation depending on its historical emissions. This practice was called 'grandfathering'. In the third phase (2013-2020), an auction mechanism was introduced which entailed a financial burden for companies that were to buy the necessary permits to pollute. At the same time, the European Commission (EC) exempted all installations operating in sectors considered particularly exposed to the risk of relocation to countries with less stringent[1]environmental policies, known as 'carbon leakage', in order to limit the transfer of emission-intensive activities outside the EU.

The relocation of high greenhouse gas emission activities outside the EU could not only lead to a failure to reduce the same emissions globally, rendering policy ineffective,[2] but could also lead to job losses in favour of countries with weaker mitigation policies. To address this drawback, plants operating in sectors exposed to carbon leakage risk continued to receive emission allowances free of charge. Figure 11.1 summarizes how polluting permits are allocated at different stages of the EU ETS.

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[1] For a list of sectors of economic activity deemed to be exposed to carbon leakage, see Decision 2010/2/EU (published 24 December 2009).

[2] The generation of greenhouse gas emissions is a global externality, and the damage it causes does not depend on the location of the emissions. This means that a pure relocation of the polluting source does not shift its negative impact (at least as far as the contribution to climate change is concerned).

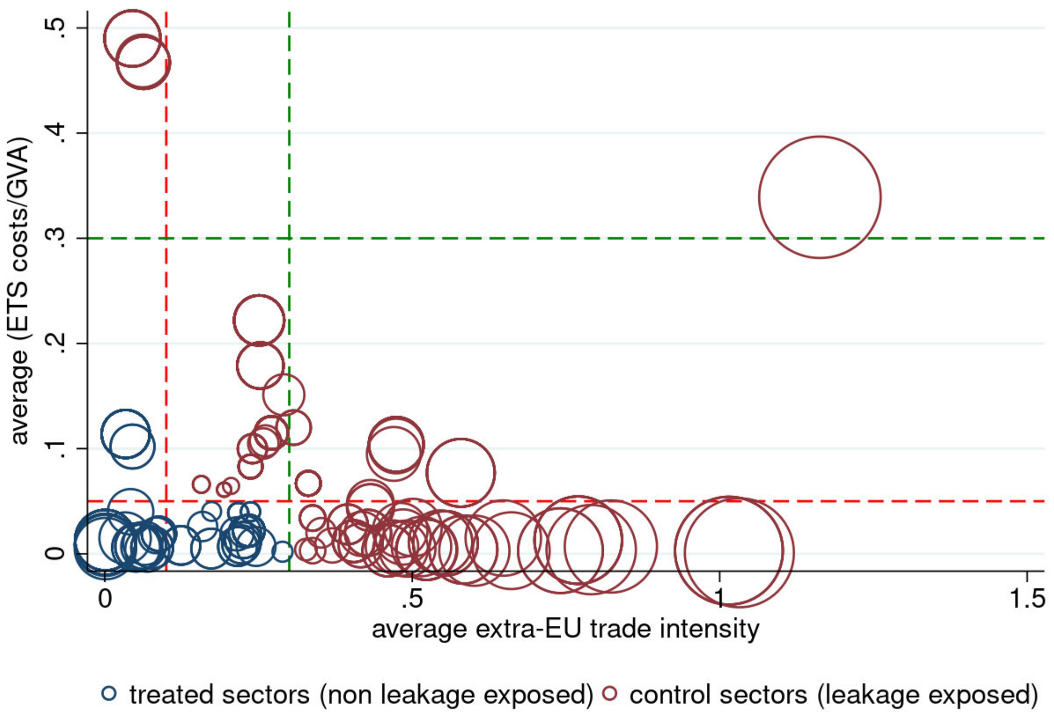
Figure 11.1 Phase of the EU ETS

Phase of the EU-ETS	Leakage sectors	Non-leakage sectors
Phase I (2005-2007)	Emission allowances are given for free to treated installations (grandfathering)	
Phase II (2008-2012)	Emission allowances are given for free to treated installations (grandfathering) Policy remains unchanged	Policy change
Phase III (2013-2020)	Emission allowances are given for free to treated installations (grandfathering)	**Treated installations do not receive free allowances, that need to be purchased in auctions (or on the spot market)**

From grandfathering to auctions: the effects of the reform. — In our work (Dal Savio *et al*., 2022) we analysed the effect on firms' productivity and foreign trade of allocating EUAs through auctions. The study focuses on a sample of Italian manufacturing companies with net revenues above €10 million and with at least one installation subject to the EU ETS, for which both balance sheet data and foreign trade data were available from Cerved Group and the Italian Customs Agency respectively.

We compared two groups of firms both subject to the EU ETS: those that have had to buy emission allowances since 2013 with those operating in sectors considered to be at risk of carbon leakage, which continued to receive the permits free of charge. More specifically, as shown in Figure 11.2, in order to be exempted from the purchase of quotas, companies had to operate in sectors (1) that would experience an increase of at least 30 per cent in the ratio between production costs and value added as a result of the higher costs generated by the implementation of the Directive (green horizontal line); or (2) have a trade intensity (import+export) with non-EU countries above 30 per cent (vertical green line). The criteria also provided for the exemption of active companies in sectors which would experience an increase in production costs on value added only above 5 per cent, provided that the trade intensity with non-EU markets was above 10 per cent (red lines).

Figure 11.2 Italian manufacturing plants by allocation rule



Note: Each circle refers to a sector; the size of the circle represents the number of Italian ETS plants in each sector. Treated sectors (blue circles) are positioned below or to the left of the blue line; control sectors (red circles) are those shown above or to the right of the same line.

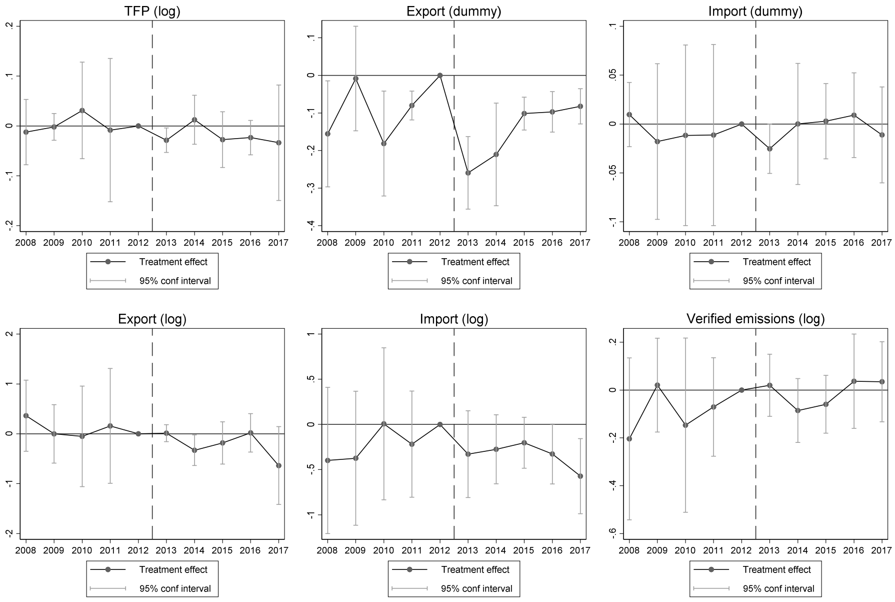
To understand the extent to which the reform of the EU ETS had an impact on business performance, we considered several outcome variables. We focused in particular on verified emissions,[3] total factor productivity (TFP)[4] and measures of international trade.

The methodology used for the analysis is based on different versions of the differences in differences approach. We first estimated a model that compares the performance of companies subject to policy change with that of exempted companies but with similar characteristics before the introduction of the EU ETS. We then repeated the analysis by narrowing our focus to firms close to the thresholds for exemption from the auction mechanism.

[3] The emissions of establishments subject to the EU ETS shall be verified by an accredited body every year.
[4] TFP is a measure of the efficiency with which companies combine their inputs.

Figure 11.3 Impact estimates of Phase III of the EU ETS

(percentage changes and percentage points)



Note: The figure shows estimates of the effect of EUA allocation through auctions in phase III of the EU ETS on total factor productivity (TFP), international trade and verified emissions of Italian manufacturing companies subject to the EU ETS. Estimates obtained by diff-in-diff methods combined with propensity score matching.

Sources: Cerved Group, the Italian Customs Agency and the EUTL (European Union Transaction Log).

The results of the analysis (Figure 11.3) indicate that the allocation of EUAs through auctions did not have a significant impact on verified pollutant emissions.[5] This means that while the EU ETS envisages a gradual reduction in the emissions allowed each year to meet the EU targets, there is no significant difference between companies that have continued to receive a free allocation of allowances and those that have had to buy them since 2013. This evidence is in line with the economic theory: since the price of a permit represents an opportunity cost whether it is received free of charge (as it can be sold on the market) or is purchased, in both cases the company chooses the level of emissions for which its marginal cost of abatement is equal to the price of the permits.[6]

The results also point to the absence of significant effects in the transition to the third phase of the EU ETS, both on total factor productivity and on companies' access to international markets, as well as on their performance on foreign markets (Figure 11.3).

Conclusions. — The evidence presented in this work enriches the previous literature, in which we notice that the impact of the EU ETS on firms' performance was assessed by comparing companies subject to the ETS to firms outside the scheme. Among these works, Marin *et al*. (2018) show that the EU ETS had a positive effect on the performance of manufacturing companies in the first two phases of the policy, particularly as regards their growth, capital accumulation and productivity; they also find an increase in firms' markups, suggesting that companies have succeeded in transferring the higher costs of the ETS to consumers or to downstream businesses in their supply chains.

[5] The same result was recently achieved by Zaklan (2022) for energy companies.

[6] What differs in the two cases, however, is the total costs, obviously lower if the permits are allocated free of charge. These theoretical results date back to Montgomery (1972).

Our results are obtained by comparing companies all subject to the ETS, which only differ because some were exempted from the auction mechanism. Moreover, in some comparisons, the parameters according to which companies obtain exemptions are only slightly different between exempted and non-exempted firms. Our results are therefore derived through an empirical strategy that can be considered very credible. At the same time, they confirm findings from previous studies. Firms subject to the auction mechanism have likely developed ways to increase efficiency in their production processes, allowing them to safeguard their productivity and competitiveness on the international markets.

It should also be noted, however, and this is an important point if one wishes to extend the estimated effects to the most recent years, that the analysis refers to a period when the unit price of EUAs was below €10. It is therefore unclear whether results would still hold in the current situation with much higher prices (close to €80 in 2022).

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12. FOSTERING DECARBONIZATION: SIMPLIFYING AUTHORIZATION AND DEPLOYING RENEWABLE ENERGY SOURCES IN ITALY

Federica Daniele,[*,a,b] Alessandra Pasquini,[a] Stefano Clò[c] and Enza Maltese[a]

Classification of JEL: H23, K32, L51, Q42

Keywords: investments in the photovoltaic sector, regulatory simplification, regions.

Introduction. — Achieving carbon neutrality by 2050 requires a thorough overhaul of the energy production system, which is still heavily dependent on fossil fuels (72 per cent in Europe and 83 per cent in Italy). Renewable electricity sources (RES-E), and photovoltaic (PV) sources in particular, will have to make the main contribution to achieving environmental targets. The Italian National Energy and Climate Plan (NECP) plans to increase the share of energy produced from renewable sources by at least 20 percentage points, from 35 per cent in 2019 to 55 per cent in 2030. The main contribution to this growth is expected to come from photovoltaic (PV) energy, whose share in the renewable sources mix is expected to rise from 8.9 per cent in 2019 to nearly 40 per cent in 2030, for a total of 29 GW of additional installed capacity.

The increase in the share of renewable sources is desirable not just from an environmental point of view: the installation of photovoltaic panels for self-consumption would give companies, especially those operating in energy-intensive sectors, greater resilience to the marked increases in electricity prices, such as those experienced throughout Europe starting in the second half of 2021.

As shown in Figure 12.1, after a period of fast growth also supported by generous economic incentives, annual installations of photovoltaic energy systems stagnated in the years 2014-2020, despite the sizeable decrease in production costs.[1] The weak performance of installations in recent years contrasts strongly/markedly with the NECP's ambitious objectives.

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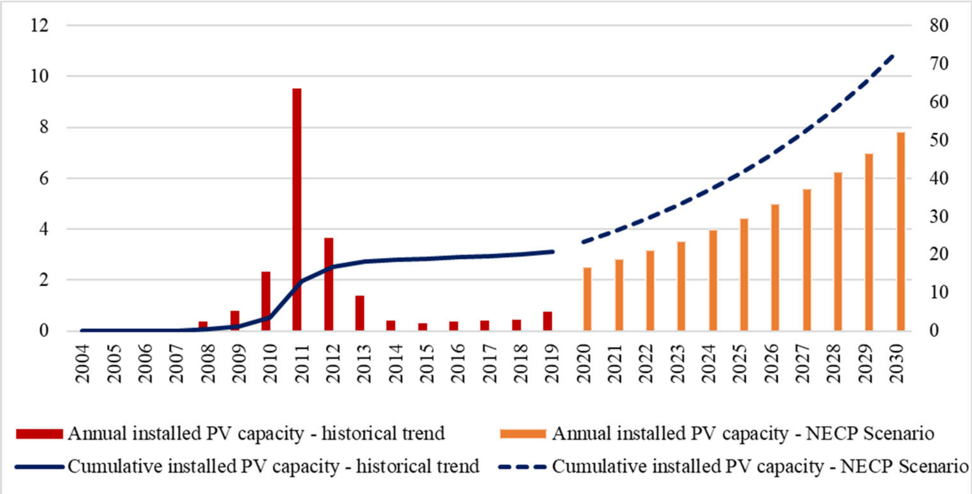
[1] The average cost of energy for the construction and maintenance of large plants (utility-scale) decreased by 82 per cent from 2010 to 2019 (IRENA, 2020).

Figure 12.1 Installed capacity (annual and cumulative) and projections for NECP installations



Note: The graph shows the evolution of annual installed capacity (left-hand scale) and cumulative installed capacity (right-hand scale) in Italy. From 2004 to 2019, it shows the actual pattern, from 2020 to 2030 it shows the installations required to achieve the NECP's goals under the assumption of/assuming a steady increase in the installed capacity over the years.

Source: Authors' calculations based on Gestore dei Servizi Elettrici (GSE SpA) data.

The cumbersome and lengthy authorization procedure to build new plants is among the main obstacles to the diffusion of photovoltaic energy. In our recent work (Daniele *et al.*, 2022), we provide an evaluation of the effectiveness of a series of simplifications in the authorization procedure introduced by a group of Italian regions in the years 2009-2013 in favour of plants with an installed capacity of between 20 and 200 kilowatts (kW).[2] These simplifications exempted medium-sized plants from the obligation to obtain the Autorizzazione Unica (single authorization, AU) substituting it with a leaner procedure, normally restricted to smaller installations (simplified authorization procedure, PAS). The AU, as originally established by Legislative Decree 387/2003, was required for all plants above 20 kW, and involved a long and burdensome process. To obtain the authorization, the applicant has to provide a long list of documents (such as: proof of coherence with the existing town planning, analytical description of the production cycle of the plant, energy balance report, expected annual electricity production, report on expected net emissions), requiring the consulting of different types of experts. The documents are examined by a number of local, regional and national stakeholders and authorities ('Conferenza dei servizi'). As an example, it took nearly three years to obtain an AU in the region of Puglia to build a photovoltaic plant with an installed capacity above 1 megawatt (MW) at the beginning of 2008.[3] The PAS, instead, takes much less time (maximum 30 days), and costs less too.

In 2011, the Government enacted the simplification decree known as Decreto Romani (Legislative Decree 28/2011) which, among other things, allowed the regional Governments to introduce exemptions from AU for plants up to 1 MW and also authorized the simplification actions undertaken by some regions in previous years. Between 2009 and 2013, a series of regions introduced the exemption from the AU for plants between 20 and

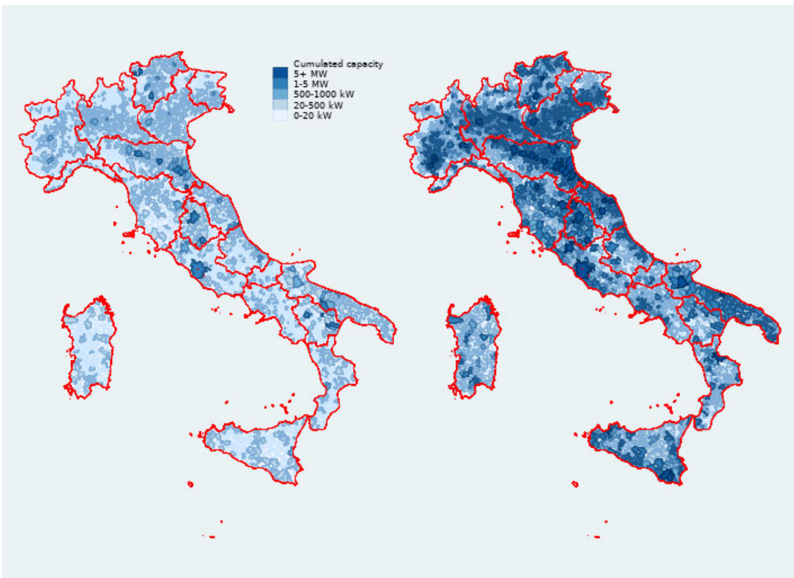
[2] The installed capacity of an energy plant is measured in kW. A 10 kW plant (or more generally 10 kW of installed capacity) produces, under optimal conditions (and therefore in production peaks), 10 kWh of energy.
[3] https://www.sistema.puglia.it/portal/page/portal/SistemaPuglia/AutorizzazioneUnica.

200 kW: Abruzzo, Basilicata, Calabria, Emilia-Romagna, Friuli Venezia Giulia, Lombardy, Trento, Umbria and Veneto.

Several studies have analysed the impact of regulatory simplification on economic activity (Helm, 2006; Fadic *et al.*, 2019). Those focusing on the Italian economy (Accetturo *et al.*, 2017; Giacomelli and Menon, 2017; Giordano *et al.*, 2020) highlighted that the certainty of procedural time length (measured as contract execution following legal disputes) and the efficiency of the public administration affects the average size of the companies, their growth and productivity positively. On the other hand, few works analyse the regulatory simplification in the context of energy production from renewable sources (Giaccaria and Dalmazzone, 2012; Wanga *et al.*, 2019). They mainly focus on the analysis of socio-economic and environmental determinants of the spread/birth of enterprises in this sector, such as economic incentives, sunlight exposure (solar radiation) and economic development (Germeshausen, 2018; Monarch *et al.*, 2018; Caneppele *et al.*, 2013; Dharshing, 2017). The studies that investigated the impact of the regulatory framework, on the other hand, highlighted that an excessively high burden of compliance with stringent environmental regulations could weaken the incentive to invest. The decentralization of authorization procedures, instead, has a positive impact, due to the greater knowledge of the territory by local institutions, which improves the effectiveness of the process.

Data on photovoltaic systems. — We rely on micro-data provided by the Gestore dei Servizi Elettrici (GSE SpA), covering nearly the entire universe of Italian renewable energy plants having benefited from national incentives. A comparison with Terna SpA data on all renewable energy plants reveals that the GSE database accounts for 92.4 per cent of the photovoltaic capacity installed in Italy in the years 2009-2013.

Figure 12.2 Installed capacity per municipality (cumulated)



Note: The figure shows the cumulative installed capacity by municipality due to the construction of plants with capacity between 20 and 200 kW in 2009 (left-hand map) and 2013 (right-hand map).

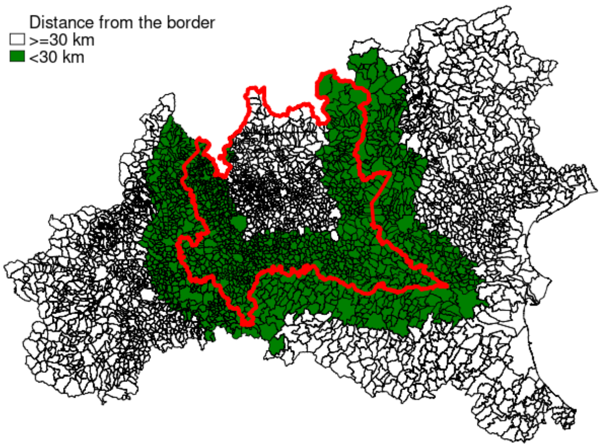
Source: Authors' calculations based on GSE SpA data.

We focus on the period between 2009 and 2013, the years of the 'photovoltaic boom'. During this period, the Italian *feed-in-premium* incentive mechanism was in force, known as the 'Conto Energia'[4] and about 90 per cent of the installed capacity implemented between 2005 and 2020 was installed. Figure 12.2 shows the distribution, in 2009 (left-hand map) and in 2013 (right-hand map), of the cumulative installed capacity of photovoltaic plants between 20 and 200 kW, which amounted to 30 per cent of the capacity installed during that period.

A comparison between areas. — Our analysis aims at comparing the increase in photovoltaic installations in the period following the introduction of simplifications compared with the previous period, in regions that have implemented the reform against the neighbouring ones that have not and at focusing exclusively on municipalities located within 30 kilometres of the regional border. To provide a general example, in Figure 12.3 we highlight the municipalities used in our analysis when focusing on the region of Lombardy. This approach allows us to separate the impact of simplifying authorizations from that of other factors that may have influenced the installation of photovoltaic systems.

The focus on municipalities near the border guarantees a comparison between similar territories from the point of view of both morphology and socio-economic characteristics. Indeed, neighbouring municipalities have access to the same services and constitute highly interconnected economies, regardless of their region. For example, Lombardy, one of the first regions to introduce the reform, is 47 per cent flat and is therefore a territory that — regardless of simplification policies — would be more favourable to the development of photovoltaic plants than its mountainous neighbour Trentino Alto-Adige. Disregarding these differences would lead us to overestimate the impact of simplification policies.

Figure 12.3 Municipalities included in the estimation of the impact of regulatory simplification



Note: The green areas highlight the municipalities included in the estimation of the impact of the regulatory simplification for the Lombardy region.

Source: Authors' calculations based on ISTAT data.

[4] The Energy Account is a European programme to encourage the production of energy from photovoltaic sources. In Italy, it has been divided into five rounds of economic incentives from 2005 to 2013. According to the feed-in-premium system, operators sell the energy produced directly on the electricity market and receive a payment per unit of installed capacity from the state, either fixed or dependent on the price of electricity, to insure operators against price fluctuations in the latter case (see https://www.gse.it/servizi-per-te/fotovoltaico/conto-energia).

A more sustainable bureaucracy. — Our results suggest that regulatory simplifications increased the installed capacity in municipalities along the border by 29 per cent in the regions introducing them. The overall contribution of the simplification reforms was an additional 12 MW per quarter during 2009-2013, around 10 per cent of installed capacity in plants with a capacity of between 20 and 200 kW during that period. We also analysed how the estimated effect changed with respect to some important territorial characteristics: the level of solar radiation of the areas and the level of efficiency of local public institutions. A higher estimated effect in areas with higher solar radiation levels would suggest that simplification policies also favour a more efficient distribution of photovoltaic energy over the territory. However, the lack of significant differences in the estimated effect does not support this hypothesis. The estimated effect does not change the level of efficiency of local public institutions significantly either, suggesting that simplification reforms do not benefit (harm) areas that already have greater (lesser) administrative efficiency.

However, the increase in plant installations between 20 and 200 kW may not result in a general increase in installed power/capacity. For example, it could have displaced the installations of plants of other dimensions. Let us think of a company that needs to install a 20 kW photovoltaic plant for self-consumption: without administrative simplification, the company would choose to install a 19 kW plant to avoid the burdens associated with an AU, while in the presence of simplification, it decides to build a 20 kW plant. In such a case, the effect we measure could be the result of an increase in the installations of 20 kW plants or bigger to the detriment of 19 kW plants, rather than being a real increase in the overall production of energy from renewable plants. However, additional analysis suggests that our results are not affected by this ‘selection’.

Another phenomenon that could artificially inflate our results is that of investors moving the plant construction site from one side of the border to the other in order to benefit from a leaner authorization regime. For example, an entrepreneur from the Piedmont region living near the border with Lombardy who wants to build a plant to produce photovoltaic energy above 20 kW could decide to install it in Lombardy, if this region has already introduced the simplification reform and Piedmont has not. If so, the effect we measure could be the result of an increase in the installation of the plants located in Lombardy to the detriment of those located in Piedmont, rather than a real increase in installed capacity at national level. Our additional analyses show, however, that there is no evidence of such relocations.

The results of our study show that a simplification of the authorization procedures, aimed at reducing the timeframe, burdens and uncertainty associated with the construction of a medium to large photovoltaic plant, can be a valuable tool for achieving the ambitious objectives imposed by the NECP. These results validate the strategies of the NECP and the National Recovery and Resilience Plan, which include interventions for regulatory simplification among those that must be implemented to achieve the goal of increasing installed capacity from renewable sources.

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13. THE POTENTIAL DISTRIBUTIONAL EFFECTS OF A TAX ON GREENHOUSE GAS EMISSIONS IN ITALY

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Classification of JEL: E60, H23

Keywords: carbon taxation, inequality, double-dividend hypothesis, green transition, redistribution.

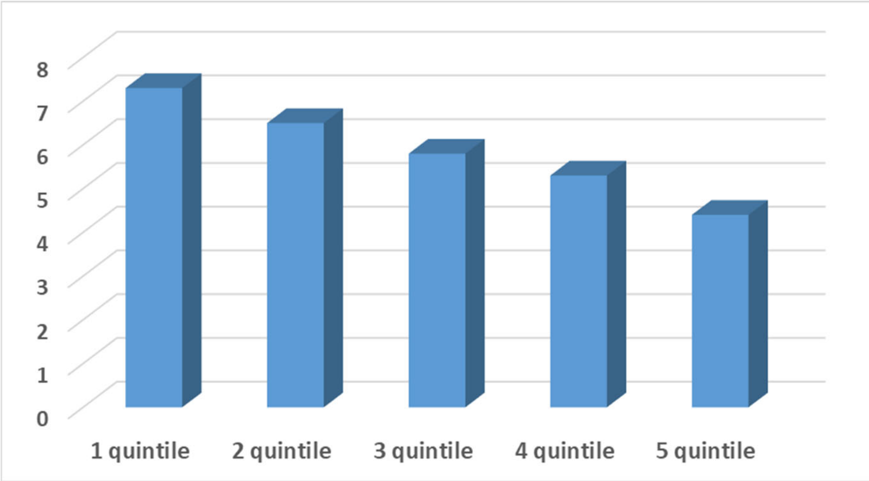
Introduction. — On 17 January 2019, the Wall Street Journal published the most important public statement by economists in history, signed by 28 Nobel laureates, 4 former Presidents of the Federal Reserve Board and 15 Presidential Economic Advisors. The declaration states that a carbon tax provides the most cost-effective lever to reduce greenhouse gas emissions at a pace necessary to limit the effects of climate change.[1] Moreover, in order to maximize the political feasibility of such a tax, all revenues should be directly rebated to citizens.

This explicit reference to equity considerations stems from the fact that the introduction of a carbon tax often does not have a broad public consensus. On the contrary, on some occasions, opposition to this measure has resulted in violent street demonstrations. In November 2018, the *gilets jaunes* movement, born from protests against rising fuel prices due to some environmental tax measures, provoked several clashes in France (Douenne *et al.*, 2020). As a result of these protests, the amount of the carbon tax, which should have increased in the following years, remained frozen until 2021.

The underlying reasons for these demonstrations are essentially linked to the fact that poorer households spend a relatively higher fraction of their income on purchasing energy-intensive goods than richer ones; as a consequence, their purchasing power is more sensitive to changes in energy prices. According to Eurostat data, the relative share of energy expenditure is clearly decreasing along the income dimension. In 2015, EU citizens in the first quintile of income used more than 7.3 per cent of their spending for electricity and gas, compared with the 4.4 per cent spent by the top quintile.

[1] The European Environment Agency estimates that cumulative GDP losses due to extreme weather events between 1980 and 2019 amounted to around 3 per cent of the GDP of member countries in 2019.

Figure 13.1 Share of expenditure on electricity, gas and other fuels for income quintiles in the EU (as a percentage of total expenditure)



Source: Eurostat 2015 data.

Heterogeneity is relevant not only on the demand side, but also on the supply side. Baccianti (2013) finds great heterogeneity across sectors in the estimated value for the elasticity of substitution of energy with other inputs at European level. This implies that some companies are better prepared than others to substitute energy with capital and labour, allowing them to be shielded from an increase in energy prices.

The model and the carbon tax as proposed by the main international institutions. — Our work (Caprioli and Caracciolo, 2022) studies how the redistribution of revenues resulting from the introduction of a carbon tax can make it more socially acceptable, thus favouring the necessary support for environmental policies. To this end, we use a general equilibrium model which, unlike the partial equilibrium analyses in the literature, makes it possible to explicitly take into account behavioural responses to an increase in energy prices, as well as how it spreads to the prices of other goods and wages. The model is calibrated on Italian data to capture the distribution of income across households, some features of the tax system in place and the interlinkages across sectors in the production network. It is sufficiently rich in terms of heterogeneity to account for the empirical evidence described above.

In the model, we introduce a carbon tax equivalent to $75 per tonne of CO_2, the amount recently proposed by the IMF Director General and deemed necessary to contain the temperature increase to less than 1.5 °C compared with pre-industrial averages. The strategy of modelling this measure as a tax on energy imported from the rest of the world is consistent with the recent proposal by the European Commission to introduce a differentiated pricing mechanism for imported goods according to their emissions content.[2]

In our framework, an increase in energy prices has an impact through two distinct channels. First, the purchasing power of the poorest households is reduced relatively more than that of the wealthiest households, as the former spend a higher fraction of their income on purchasing energy-intensive goods and services. Secondly, in the face of an increase in intermediate production costs, firms' demand for other inputs changes. These adjustments, which depend on the specific technological possibilities of each sector, have an impact on

[2] More details about the proposal can be found at https://ec.europa.eu/taxation_customs/green-taxation-0/carbon-border-adjustment-mechanism_en.

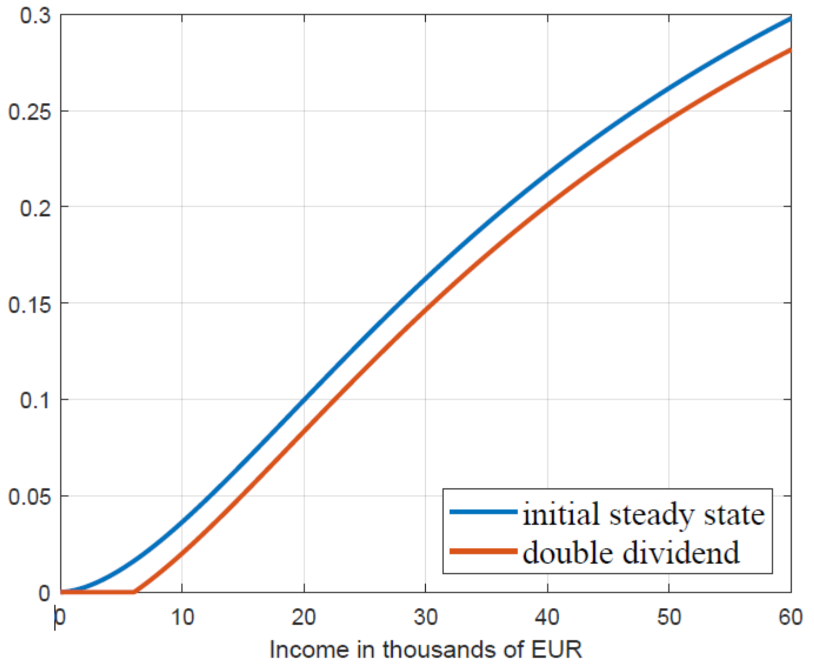
the remuneration of labour and capital, thus affecting the disposable income of consumers, depending on their sector of employment.

The policies examined. — In order to address the distributional effects of these two mechanisms, we assume that the government can use the revenues linked to the new tax in three alternative ways, namely to finance:

1. an increase in public expenditure;
2. redistribution through uniform transfers;
3. a reduction in the labour income tax (Irpef), which results in a uniform change in average effective rates, as shown in Figure 13.2.

Using the proceeds of the carbon tax to reduce the burden of distortionary taxation on labour income follows the logic of what the literature identifies as the double dividend hypothesis. According to this hypothesis, the benefit from this type of policy would be twofold: on the one hand, it counteracts the effects of climate change, and on the other hand, it improves economic efficiency by reducing distortions due to taxation.

Figure 13.2 Average Irpef tax rates pre (blue line) and post (red line) carbon tax

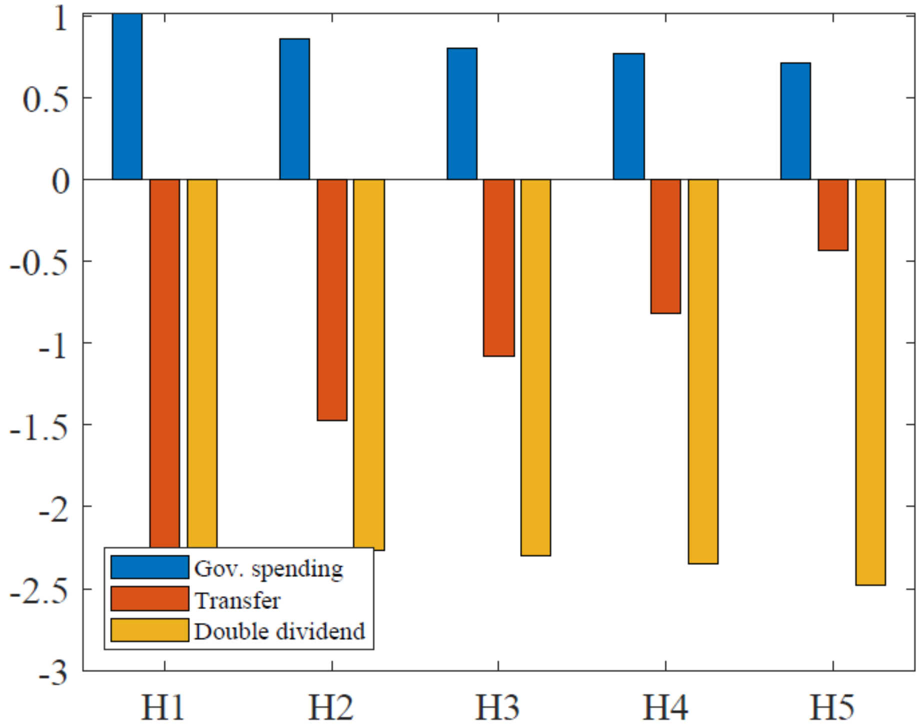


To identify the impact of each of these redistributive policies, we consider two alternative assumptions for the functioning of the labour market: under the first, perfect labour mobility allows workers to take advantage of more favourable employment opportunities, if the impact of the carbon tax reduces relative wages in their sector of employment. On the other hand, this possibility is precluded under the second hypothesis, in which workers cannot switch to another sector. Although they represent two extreme cases, the scenarios analysed are useful in framing the role of labour market distortions in shaping the outcomes of the three different redistributive policies.

Our analysis focuses on the long-term effects of each policy on welfare across the different quintiles of income distribution. The impact of each policy on welfare is measured in terms of the equivalent variation in consumption, i.e. the amount of consumption that agents would be willing to waive in order to avoid the introduction of the tax and the associated redistributive scheme. When this variable is positive, the policy change has a negative effect on the welfare of workers. On the contrary, a negative value is a sign of a welfare gain. The results show that the policy that produces the largest welfare gains depends on the degree of mobility in the labour markets.

The results in the case of perfect labour mobility. — When workers can move freely across sectors, the main findings of the study are:

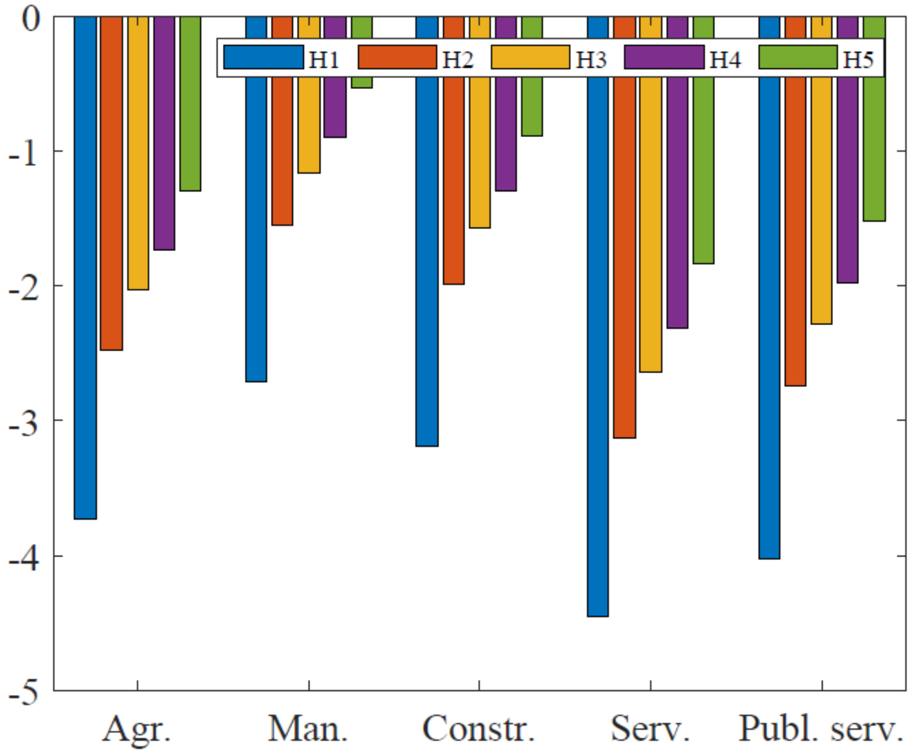
Figure 13.3 Consumption equivalent variation per quintile of income distribution depending on the redistribution scheme, under the perfect labour mobility scenario



1. Using carbon tax revenues to finance an increase in public spending is not sufficient to counterbalance the worsening welfare conditions of workers due to the environmental tax in the long run; under our calibration of the model, higher public spending actually implies very limited increases in labour demand by firms and in wages (see the blue histograms in Figure 13.3).
2. In contrast, using carbon tax revenues to reduce Irpef or making uniform transfers increases the long-term welfare of all agents. In the case of uniform transfers, the benefit is greater for individuals in the first quintiles of income distribution (see the red histograms in Figure 13.3); for these agents, the effects of the transfer on disposable income are significantly more favourable than those associated with the new tax. In absolute terms, they contribute to a lesser extent to the revenues of the carbon tax, while spending a greater fraction of their income to purchase energy than individuals belonging to the other quintiles. In the case of a reduction in the average tax rates, the benefit is, by construction, distributed in an almost uniform manner across workers belonging to the different income quintiles and. At the aggregate level, it is higher than that relating to the previous scheme (see the yellow histograms in Figure 13.3). This result is due to the fact that a highly distortionary tax on labour supply is replaced with a less distortionary levy on energy consumption (overall less elastic to price changes).

Results in the case of a segmented labour market. — In the scenario characterized by segmented labour markets where workers are not allowed to change sector of employment, the carbon tax has a heterogeneous impact on wages.

Figure 13.4 Consumption equivalent variation per quintile of income distribution under the assumption of uniform transfers in the case of segmented labour markets



Under this hypothesis, the introduction of a carbon tax depresses economic activity more than in the previous case. In fact, workers are unable to reallocate in sectors with higher wages (i.e. those less affected by higher energy prices), and are forced to increase labour supply (as opposed to the case of flexible labour markets); this amplifies the depressive effect on the equilibrium wages.

In this context, using carbon tax revenues to finance an increase in public expenditure has qualitatively similar effects to what happens when there is a flexible labour market. Redistribution through uniform lump-sum transfers leads to an increase in income compared with the situation prior to the introduction of the carbon tax, as the negative effects of the contraction in hours worked are more than offset by the positive ones associated with the increase in the unitary equilibrium wage. Overall, this redistributive scheme leads to an improvement in the welfare of all workers (see Figure 13.4). On the other hand, redistribution by reducing Irpef rates is not sufficient to compensate for the effect on incomes due to the introduction of the carbon tax. Indeed, the negative impact of the carbon tax on economic activity significantly reduces Irpef's tax base. Therefore, the government budget constraint does not provide a sufficiently large reduction in tax rates. It follows that the welfare of all workers decreases.

Conclusions. — Our study examines the long-term distributional effects of several policies that can be activated when a carbon tax is introduced in Italy that is equivalent to \$75 per tonne of CO_2 in order to recycle its revenues and rebate them to the population. An increase in energy prices linked to the introduction of a carbon tax affects poorer households and businesses in sectors where it is more difficult to replace energy with other inputs. However, in order to study the redistributive effects of a carbon tax, it is crucial to take into account both how the revenues are redistributed by the government and the structure of the labour market.

Our study shows that, following the introduction of a carbon tax in Italy, it is possible to implement redistributive policies that increase the long-term welfare of workers. The analysis highlights, among other things, the impact of labour market distortions on the most appropriate tool to make a socially acceptable carbon tax. In general, under the assumption of segmented labour markets, the carbon tax would shrink economic activity more than in the case of perfect labour mobility.

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14. WASTED IN WASTE: THE BENEFITS OF SWITCHING FROM TAXES TO PAY-AS-YOU THROW FEES: THE ITALIAN CASE

Giovanna Messina and Antonella Tomasi*

Classification of JEL: D78, H23, H71, Q53

Keywords: pay-as-you-throw, municipal waste management, policy evaluation.

Introduction. — Municipal waste management is one of the main services provided by local authorities and accounts for about a quarter of the current expenditure of Italian municipalities (nearly €10 billion). In most cases, the service is financed by a local real estate tax (waste tax, TARI) based on the surface area of the dwelling and the number of members in the household. Alternative financing systems, called 'pay-as-you throw' (PAYT) are instead designed to price each additional unit of waste produced by the user. This user-pricing model is also one of the cornerstones of the European Circular Economy Strategy and one of the priorities of NextGenerationEU, which sets ambitious targets in terms of separate collection and material recovery rates as well as stringent limits on landfill waste disposal. Despite a widespread implementation at international level, the adoption of PAYT systems is still very limited in Italy. Our study (Messina and Tomasi, 2020) aims to assess the effects of a large-scale application of PAYT tariffs by Italian municipalities.

A large strand of research, initiated by Wertz's contribution (1976), highlighted the efficiency benefits of PAYT schemes linked to lower waste generation. PAYT fulfils a signalling role similar to that of a market price, on the demand side, encouraging users to request the optimal amount of public service (unlike what would happen if the service was financed with a flat tax such as TARI) and, on the supply side, local administrators to make the best use of public resources. Lower waste generation leads to significant positive externalities in terms of environmental sustainability, as it allows greenhouse gas emissions to be reduced. Issues relating to the financing of waste management also have implications in terms of equity, as highlighted in particular by Wright (2018): property tax-based financing systems mainly affect low-income households, which generate smaller amounts of waste. This topic has been analysed for the Italian case by Messina, Savegnago and Sechi (2018), who highlighted that the share of income allocated to pay the waste tax by households in the lower deciles of consumption distribution is about twice that paid by households in the upper deciles

Empirical research has documented that there is robust evidence on the negative relationship between the adoption of a PAYT scheme and the amount of waste produced by households (Bel *et al.*, 2016); in addition, systems where compostable waste is collected and charged separately, as well as those in which waste is measured in terms of weight rather than volume, seem more effective in containing waste generation. However, some factors, such as the need to make large initial investments, as well as the administrative and management costs of waste measurement technologies could hinder the adoption of PAYT systems. At the same time, unit-charging fees could increase the risks of illegal disposal or export of waste to neighbouring jurisdictions, even if several analyses show that these risks would be negligible (Card *et al.*, 2016; Linderhof *et al.*, 2001).

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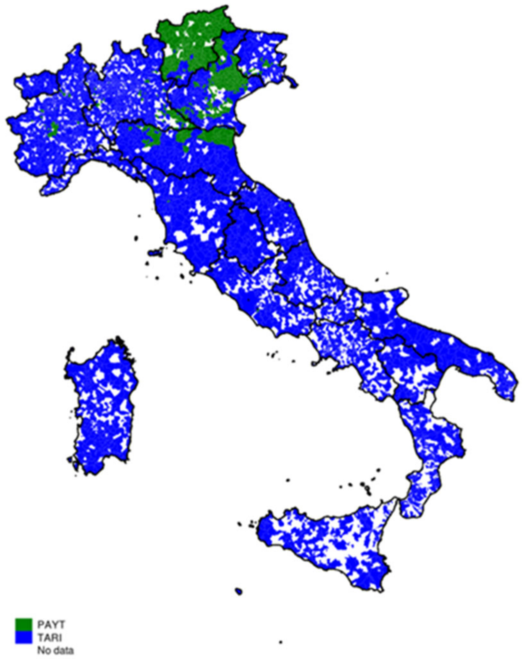
Only 10 per cent of Italian municipalities, mainly located in north-eastern regions, finance waste services by applying PAYT tariffs (Figure 14.1). Some of them use a partial unit pricing system by setting a flat 'first-tier' fee covering a given number of bags or bins to be collected and a 'second-tier' fee based on the additional amount of waste thrown away;[1] in other cases, the tariff is directly linked to the amount of unsorted waste produced by the user.

Figure 14.1 Map of Italian municipalities applying PAYT and TARI



Source: Municipal decisions, 2018.

Which municipalities use unit pricing — The starting point of our analysis (Messina *et al*., 2020) is the construction of a municipal dataset containing the information necessary to answer the following questions: how are waste services financed, what are the main features of the supply and demand for such services and what are the structural, institutional and political characteristics of the institutions?

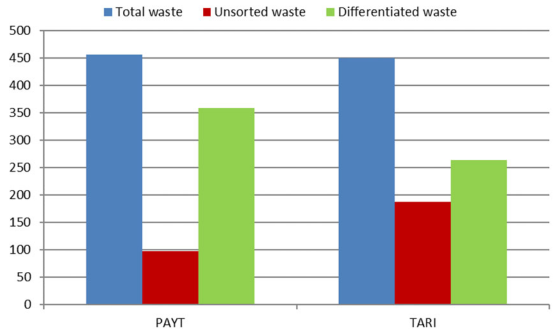
We examined the decisions of individual municipalities, dividing them into two groups according to the application of a TARI tax or a PAYT system. The variables describing the demand (quantity and type of waste generated) as well as the supply of waste services (costs broken down by category and by type of waste, location of installations, organizational profiles) were taken from ISPRA (the Italian National Institute for Environmental Protection and Research). Finally, to take account of the peculiarities of each municipality, geomorphological and demographic data (ISTAT, the Italian national institute of statistics), economic variables (Ministry of Economy and Finance) and political-institutional aspects (Ministry of the Interior) were added. Overall, the dataset includes 180 variables and 6,100 municipal observations.

A first descriptive analysis shows that PAYT municipalities do not differ substantially from the TARI group in the production of waste, but have significantly higher rates of separate collection (almost 80 per cent, compared with 60 per cent for the TARI group; Figure 14.2a).

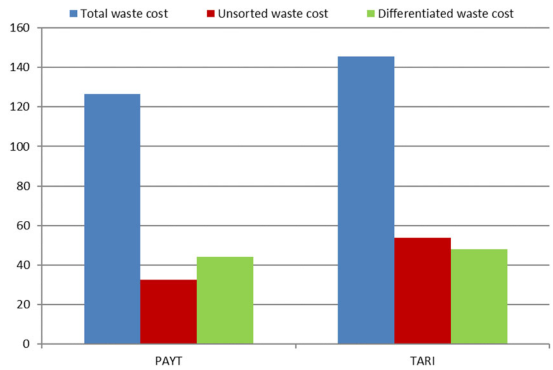
[1] In the municipality of Reggio Emilia, for example, a family unit of 2 people has a minimum size of 18 containers for collection per year (40 litres per container) and the cost of each individual collection is €1.60. The charge is therefore €28.8 (18 x 1.60). Any collections in addition to the minimum of 18 are charged as and when they are carried out.

Figure 14.2 Comparison by type of waste (total, unsorted and differentiated)

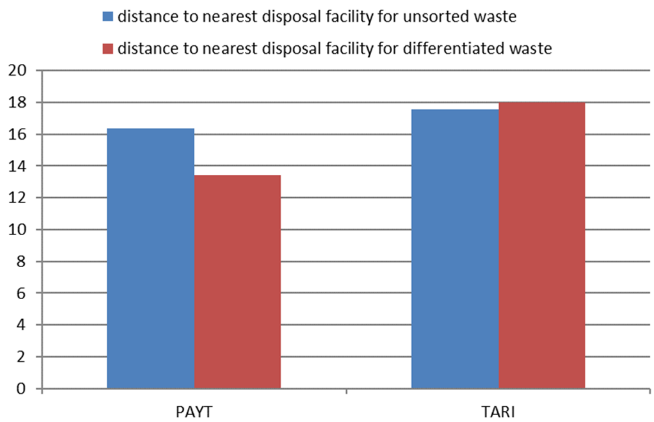
a) waste generation (kg per inhabitant)



b) waste service costs (euros per inhabitant)



a) distance to nearest disposal facility (km)



Source: Our calculations based on ISPRA data.

There are also significant differences between the two groups in terms of waste services costs: total costs amount to around €130 per capita in the PAYT group, compared with €150 in the TARI group; those relating to the undifferentiated component are 40 per cent lower in the first group (Figure 14.2b).

From a demographic point of view, PAYT municipalities appear to be smaller and less densely populated than TARI municipalities. Moreover, PAYT municipalities have more intense tourist flows (0.29 beds per inhabitant compared with 0.15 beds in the TARI municipalities) and are relatively closer to waste treatment plants, especially those for the treatment of the organic component (Figure 14.2c). Finally, PAYT municipalities are administered by mayors who are younger on average (47, against 53 in the TARI group), with a slightly higher share of women and a lower share of graduates than the TARI group (respectively 18 vs 15 per cent and 41 against 47 per cent).

The estimation of the impact of PAYT on waste generation requires a preliminary discussion of the endogeneity of the choice to adopt a PAYT system in relation to the characteristics of the municipality: it is possible, for example, that more environmentally conscious municipalities, which generate less waste, are more inclined to introduce unit-pricing fees or, on the contrary, that communities with a higher production of waste or with a low share of differentiation expect more substantial gains from PAYT systems and have a greater propensity to adopt them. Such situations could lead to overestimating or underestimating the effect of the service financing system. The problem of endogeneity could be mitigated in the Italian context by the fact that choosing how to finance the waste service often transcends the individual entity, being the responsibility of supra-municipal administrative allocations (optimal territorial areas, ATOs), which institutions are obliged to join.

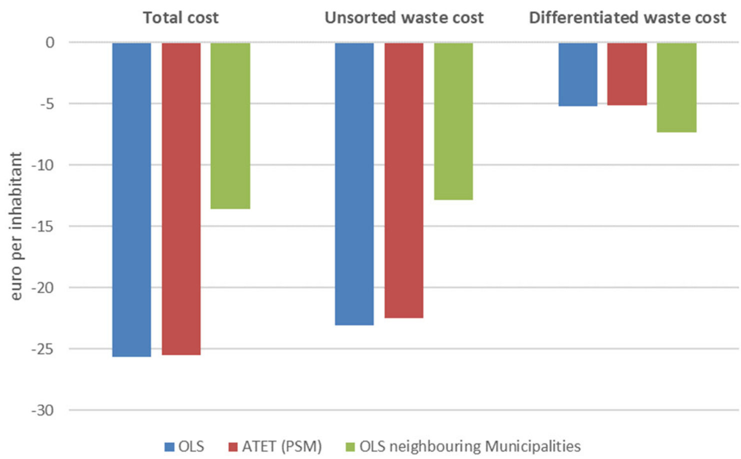
To estimate the impact of PAYT on the demand for waste services, we followed three different empirical strategies, first estimating a linear regression function and then applying statistical techniques[2] to carry out a counterfactual analysis, in which the municipalities that adopted PAYT are compared with municipalities that are completely similar in their socio-economic characteristics but that finance the service with the TARI. As dependent variables, we have considered alternatively the annual weight per capita of municipal solid waste or the cost of the service, distinguishing by type of waste. As explanatory variables, we used a dummy that identifies the method of financing the waste service (with a value of 1 for entities applying a PAYT system and 0 for those that apply the TARI) as well as numerous control variables to take into account the social, demographic and economic characteristics of the municipalities concerned.

The benefits of PAYT (and the obstacles to its adoption) — The results summarized in Figures 14.3 (a) and 14.3 b) show a significant impact of PAYT tariffs on user behaviour and seem robust compared with the different strategies followed. A widespread application of PAYT tariffs could contain/limit the production of total waste and halve that of undifferentiated waste (with an aggregate reduction of between 4 and 5 million tonnes), leading to a reduction in the management costs of this type of waste by about one third according to the most conservative estimates. The total cost savings can be estimated as between 10 and 20 per cent year-on-year (corresponding to almost €1.3 billion in absolute terms).

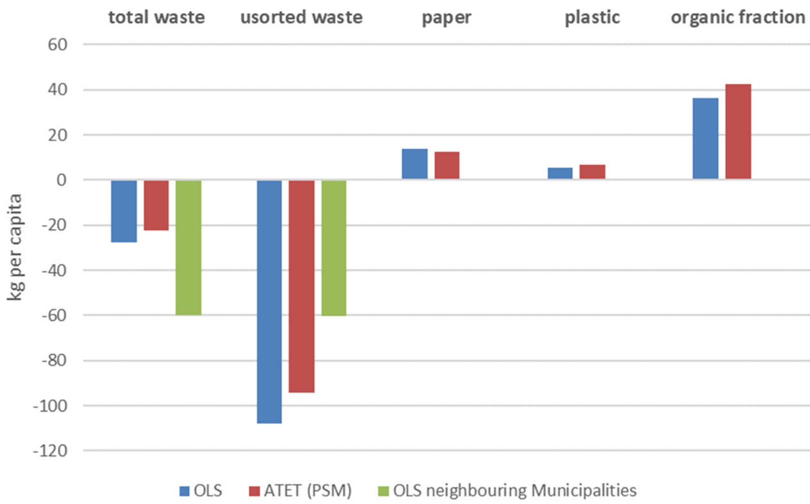
[2] Propensity score matching and regression with spatial discontinuity.

Figure 14.3 Estimations of the impact of adopting PAYT tariffs by type of waste

a) On the costs of the waste service (euros per inhabitant)



b) On the amount of waste produced (kg per inhabitant)



Note: The figures show the estimates resulting from three methodologies: linear regression (OLS), propensity score matching (ATET) and linear regression (OLS) only for the municipalities neighbouring PAYT municipalities.

Source: Our calculations based on ISPRA data.

With the shift to unit pricing, local public finance could achieve two objectives: improve the efficiency of the supply of public goods and contribute sustainably to the protection of the environment. Switching to PAYT systems is not an immediate process, however. It is only the final step on a more articulated path that requires a profound renewal in the allocation of fixed capital, the adaptation to new technologies, the sizing of the waste service on a territorial basis in such a way as to benefit from possible economies of scale, and the implementation of effective control mechanisms. Municipalities would need adequate financial and organizational resources to meet this challenge. With this in mind, the NRRP envisages investments[3] (€2.1 billion) aimed at strengthening infrastructure and digitizing municipal waste management, including through highly innovative projects to prevent

[3] In the NRRP, investments in the waste sector can be identified in the Mission "M2C1.1 Improving efficient and sustainable waste management capacity and the circular economy paradigm": Investment 1.1: Construction of new waste management disposal plants and modernization of existing plants; Investment 1.2: Circular economy 'lighthouse' projects.

illegal dumping; the interventions also aim to bridge the gap between the North and the regions in the Centre and South. The planned reforms[4] could help to simplify the current governance framework of the sector, which has a very fragmented and complex vertical division of competences.

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15. AN ANALYSIS OF THE GREEN TRANSITION IN EUROPEAN COUNTRIES BASED ON PATENTS

Roberta De Luca, Rosalia Greco and Francesca Lotti*

Classification of JEL: O31, Q40, Q50.

Keywords: innovation, patents, green transition, climate change.

Introduction. — In December 2019, a few months before the pandemic outbreak, the European Commission presented the European Green Deal, which comprises many initiatives for achieving climate neutrality in Europe by 2050. It was subsequently decided to allocate at least 30 per cent of the combined resources of the NextGenerationEU programme and the 2020-27 EU budget to climate-related projects. More recently, in July 2021, the Fit for 55 package proposed some changes to European legislation — currently under discussion at the European Council — to adapt it to the 55 per cent net emissions reduction target to be achieved by 2030. A further boost to the transition stemmed from the rise in energy prices and from the sanctions imposed on Russia as a consequence of the invasion of Ukraine; the REPowerEU plan approved in May 2022 brought the Fit for 55's emissions reduction target forward. These initiatives stress the importance, especially for policymakers, of understanding to what extent the main European countries are ready to face the challenge of the green transition; in particular, how much knowledge has been developed in the field of green innovation and what the comparative advantages of different European countries are in terms of their production.

The decarbonization process entails unavoidable transition costs, which might be reduced by technological progress; e.g. the cost of technologies for producing energy from renewable sources has largely decreased in the last decade due to technological advancements. Additionally, the green transition brings about an increase in demand for goods that incorporate greener technologies, thus representing an opportunity for growth in those areas where such technologies are developed and produced. With this in mind, in our work (De Luca, Greco and Lotti, 2021), we use patent data to assess the main European countries' performance in green innovation and the existence of specialization patterns in the production of innovations.

Measurement of green innovation using patent data. — Quantifying companies' innovative activity in a systematic way is not an easy task. The use of patents as a measure of production of innovations, as opposed to input measures such as R&D spending, was proposed by economists almost half a century ago (Comanor and Scherer, 1969). As highlighted by Lotti and Marin (2013), patent data have multiple advantages, but also some limitations. The intellectual property protection system guarantees an ex ante incentive to carry out innovative activities, by granting ex post limited monopoly rights on the invention, provided that the details about the invention are made publicly available (Nagaoka *et al.,* 2010). Besides the uncertainty embedded in the outcome of any innovative effort, the patent protection system thus adds an additional layer of complexity, as the decision to patent a new invention is a firm's strategic decision, due to the disclosure obligation imposed by the patent law. As a result, not all inventions are patented and the innovation measured through

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patents is an underestimation of the research and innovative activities actually carried out by firms.

Despite these limitations, there are multiple benefits in using patent data. The data inferred from patents are objective, as they result from an independent assessment of the 'innovative effort' made; they are homogeneous, as the patent office requires all inventions to have the same degree of 'newness' and 'non-obviousness' (innovative leap), regardless of the size and geographical location of the company that produced the innovation; they are standard, as all patents have the same format; and they are a very rich source of information about the invention and its interactions with other inventions.

These characteristics prove useful when studying green innovation, as patent data provide a measure of firms' innovative output, of its temporal trends and its geographical distribution, as well as of the interactions, interdependencies and spillovers between technologies. For instance, the Vehicle to Grid (V2G) technology (a technology connecting electric vehicles to the energy grid and exploiting batteries as stabilizers by accumulating energy when in excess and transferring it to the grid at consumption peak time) is a technology aimed at reducing emissions in the transport sector, but it also displays clear links of complementarity with the development of electric smart grids, which are infrastructures capable of pouring excess energy into the grid and managing energy flow reversals. Considering these interactions and interdependencies is therefore particularly important for policy-making and for evaluating interventions intended to promote green innovation.

In order to describe countries' technological specialization in the green patent domain, we use data from the Global Statistical Patent Database (PATSTAT) referring to patent applications filed with the European Patent Office (EPO) in the period 2000-2018 by applicants residing in the main European countries.

In international classifications, patents are organized into 'families', i.e. sets of patents relating to similar inventions and filed in different countries. Each patent belongs to one or more 'families'.[1] In order to avoid double counting, our analysis is restricted to a single patent for each family: the patent referring to the priority application, which represents the family's 'progenitor'.[2]

Following De Rassenfosse *et al*. (2013), we attribute a patent to its applicants' country of residence; when such information is missing, our algorithm uses a hierarchical approach which exploits, in sequence, data on the country of residence of equivalent patent applicants and data on inventors' locations. Patent applications with multiple applicants belonging to different countries (e.g. a patent application jointly filed by an Italian and a German company) are allocated pro-rata to both countries.

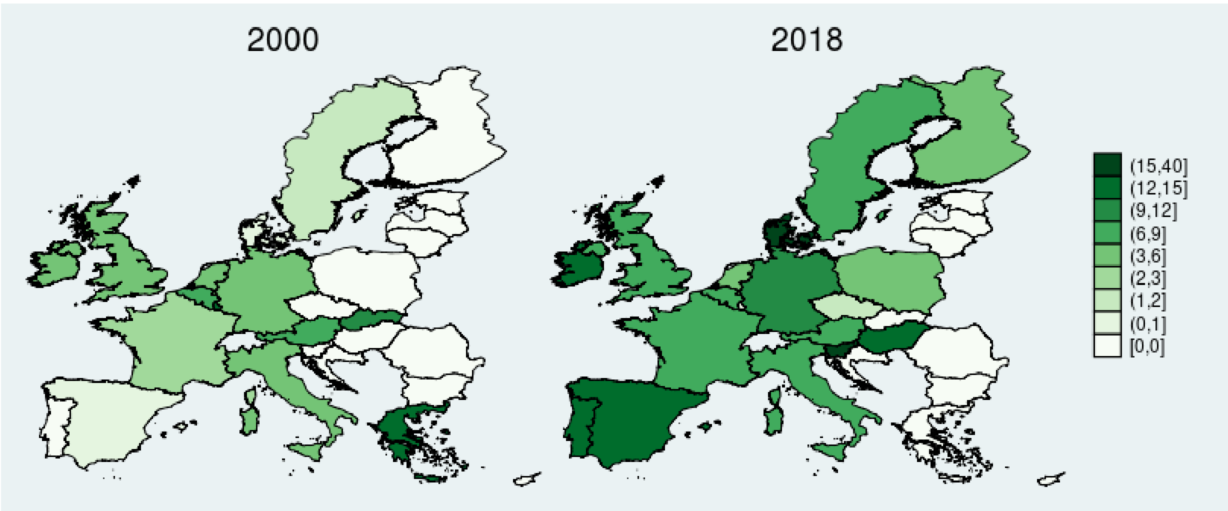
[1] The Paris Convention of 1883 on the Protection of Industrial Property set a one-year term from the initial patent application for filing the same application in other countries and claiming protection on the basis of the first filing, which is then called 'priority'. The priority's filing date (priority date) is the one used to date the priority patent as well as all subsequent patent filing which explicitly refer to it. Each subsequent patent for the same invention may refer to one or more priorities (e.g. in the case of inventions consisting of combinations of previous inventions). Priority links between patent applications create sets of patents, called 'families'. The family definition used here is based on equivalent patents, i.e. all patent applications that share the same 'priority'. Equivalent patents most likely protect the same invention; to avoid double counting, one should therefore consider only one member per patent family.

[2] Furthermore, we restrict the analysis to patent applications under the Paris Convention and the Patent Cooperative Treaty (PCT), for which the system of priorities is valid.

Green patents. — We use the Cooperative Patent Classification (CPC) scheme to identify technologies or applications aimed at counteracting climate change.[3] A patent shall be classified as 'green' if at least one of its CPC codes belongs to environmental-related technologies, i.e. classes Y02 or Y04S, covering technologies or applications aimed at mitigation of or adaptation to climate change and smart grid systems, respectively.[4] It is also possible to further split green patents into adaptation technologies, mitigation technologies and, among the latter, into technologies aimed at directly reducing the concentration of greenhouse gases in the atmosphere (through capture and storage of greenhouse gases or production of clean energy).[5] Since an invention can be associated with more than one CPC code, these categories are not mutually exclusive; e.g. the same patent can contribute to adaptation to climate change, as well as to its mitigation. We therefore apply a fractional count (similar to that used for applicants' countries) to CPC codes as well; in other words, if a patent belongs to several green classes, it is assigned pro-rata to each class.

The dynamics of the overall and green innovation activities in the period 2000-2018. In the period 2000-2018, more than 200,000 priority patent applications were submitted to the EPO by applicants from 130 countries. We restrict the analysis to the European Union's 27 current members and the United Kingdom, which jointly account for about 72 per cent of the priority applications and more than three quarters of the green patents. The number of patent applications has progressively increased over time, almost tripling between 2000 and 2018. At the same time, the number of green patents filed in 2018 is more than seven times higher than in 2000. The large territorial heterogeneity in the share of green patents in 2000 persisted through 2018, despite the generalized increase in the share in almost all countries (Figure 15.1).

Figure 15.1 Share of green patent applications, in 2000 and in 2018



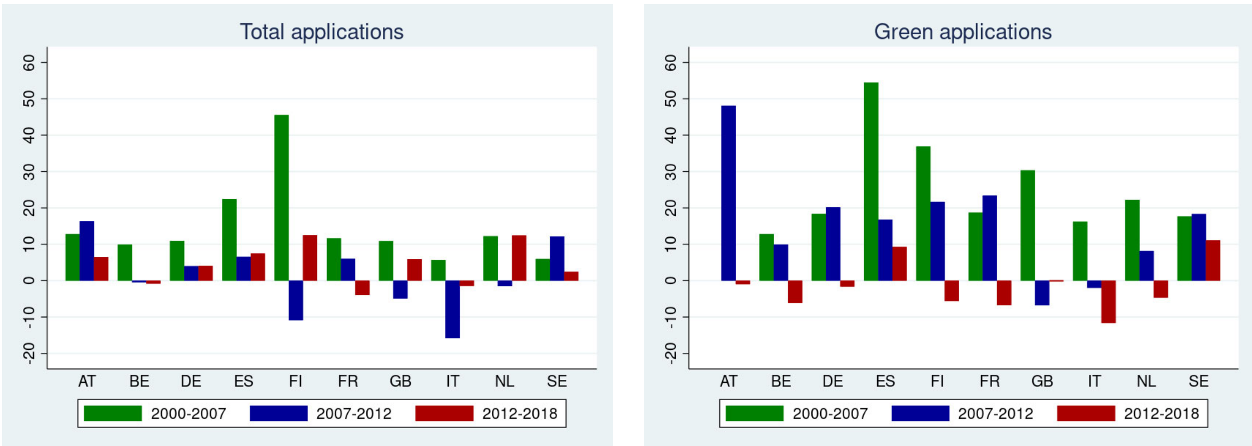
Note: Missing data for 2000 are replaced with the first available data: Latvia and Romania 2002, Bulgaria and Slovakia 2003, Lithuania 2005 and Estonia 2006. Missing data for 2018 are replaced with the latest available data: Croatia 2017.

Source: EPO Worldwide Patent Statistical Database (PATSTAT).

[3] The Cooperative Patent Classification (CPC) was introduced in 2013 and is jointly managed by the EPO and the U.S. Patent and Trademark Office (USPTO). It consists of nine sections, A-H and Y, in turn divided into classes, subclasses, groups and subgroups. Like the International Patent Classification System (IPC), of which the CPC is an extension, it aims to group patent documents according to their technical domain. Each patent can be associated with one or more CPC codes.
[4] For a discussion on the use of these CPC classes to identify green technologies, see Veefkind *et al.* (2012) and Angelucci *et al.* (2018). See also Popp (2019) for a review of the literature using this classification.
[5] Technologies aimed at reducing the concentration of greenhouse gases in the atmosphere can be traced back to the objective of mitigating the effects of climate change. However, due to their importance in all countries and their specific purpose, we decided to analyse them separately from other mitigation technologies.

The top ten countries by total number of patents (Germany, France, the Netherlands, Italy, Belgium, Sweden, United Kingdom, Spain, Austria and Finland) account for 94 per cent of patent applications and for almost 92 per cent of the green patent applications submitted by applicants from the 28 European countries considered. Among these countries, it is possible to distinguish between countries that have experienced a growing trend in inventive activity for almost the entire period in question and others that have witnessed a slowdown, especially in the last decade (Figure 15.2). In the first part of the period considered (2000-2007), all countries experienced a positive but heterogeneous dynamics of both total and green patent applications. Since 2008, there has been a slowdown in total innovative output in almost all countries, while the average growth rates of green patents continued to be sustained between 2007 and 2012 almost everywhere. However, green patenting activity also came to a halt in the most recent years of the period: the average annual growth rates between 2012 and 2018 were negative in almost all countries. Patent dynamics in Italy are qualitatively similar to those of other countries in all the sub-periods. Nonetheless, Italy is the only country registering a negative overall trend in the total number of applications submitted between 2000 and 2018 and has the lowest (although positive) annual average growth rate for green patents.

Figure 15.2 Average annual growth rates of total and green patent applications

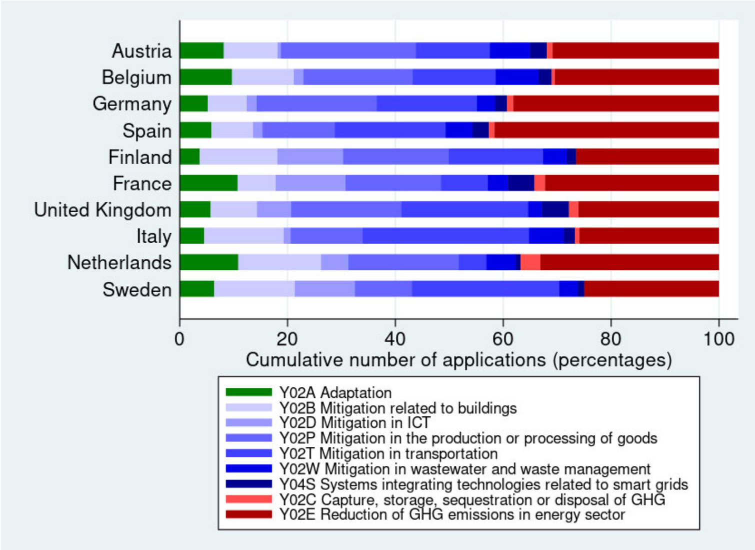


Source: EPO Worldwide Patent Statistical Database (PATSTAT).

In all countries, green technologies relating to the mitigation of climate change effects and to greenhouse gases play a significant role (Figure 15.3). Adaptation technologies have evolved more recently and still constitute a smaller aggregate; their development is mainly concentrated in France, the Netherlands, Belgium and Austria.

Figure 15.3 Cumulative number of green patent applications by technical field

(selected countries, 2000-2018)

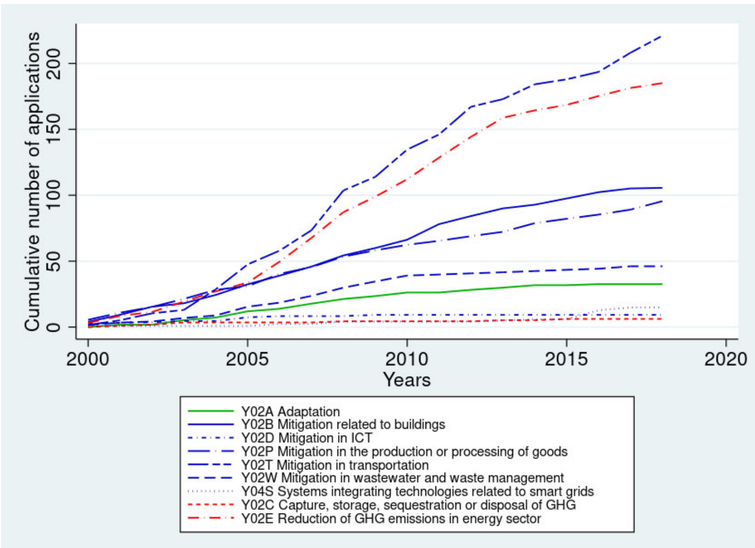


Source: EPO Worldwide Patent Statistical Database (PATSTAT).

In all countries, technologies aimed at reducing greenhouse gas emissions in the energy sector (included production of energy from renewable sources and heat utilization in the combustion or incineration of waste; Y02E) display the highest cumulative growth rate and represent the largest share of all green patent applications. With the exception of this technological class, countries' specialization in other green technical fields is heterogeneous, both in intensity and in type of technology. Beside greenhouse gas reduction, Italy is particularly specialized in mitigation strategies in the transport sector (Y02T; Figure 15.4). This class includes the development of more efficient propulsion systems and less polluting fuels, as well as design innovations in vehicles' aero- and hydro-dynamic properties. Due to their high degree of specialization in this field, Italy and Sweden are the only two countries with a higher cumulative number of patents in the Y02T class than in the Y02E class.

Figure 15.4 Cumulative number of patent applications by technical field

(Italy, years 2000-2018)



Source: EPO Worldwide Patent Statistical Database (PATSTAT).

The fields of transport and greenhouse gas emissions have clear links of complementarity: in order to effectively reduce the climate impact of the transport sector, it is necessary to develop more efficient, low-emission engines and ‘smart’ transport infrastructure that reduce traffic congestion, as well as sustainable biofuels. This consideration means that countries specializing in these two fields (like Italy) have a potential advantage in exploiting the changes brought about by the European Green Deal and the RRF. However, Italy is not the only country with a relative specialization in the transport sector;[6] additionally, as shown above, the country’s innovative activity is low and has weakened during the last decade. These two factors constitute a threat to Italy’s ability to exploit its potential advantage deriving from its specialization.

Conclusions. — The results of our analysis show that patenting activity, and therefore innovation, grew in Europe between 2000 and 2018, although with marked heterogeneity across countries. In all European countries, the green patenting time trend reflects the total patenting activity; the share of green applications does not show a significant variability over time, but it increases slightly in almost all countries over the considered period.

If we focus on innovations relating to tackling climate change, it emerges that innovative activity in Europe has reacted to the challenges posed by the energy policies of the European Union and its member states: patents relating to reducing greenhouse gas emissions in the energy sector have been increasing since the early 2000s.

However, Italy has a different patent dynamic from most other countries. Italy combines a declining patenting activity (since 2008) with a higher degree of specialization in green technologies, compared with other countries. Green patent production in Italy is particularly concentrated in innovations aimed at mitigating the effects of climate change in the transport sector and in the reduction of greenhouse gas emissions in the energy sector. These technological fields have a marked complementarity between the development of efficient, low-emission engines and ‘smart’ transport infrastructures, on the one hand, and the invention of sustainable biofuels with a lower environmental impact, on the other hand.

This evidence indicates that Italy, despite being a ‘moderate’ innovator in comparison with the other European counties, has accumulated technical knowledge in the field of renewable energy sources and transport. This knowledge accumulation represents a potential advantage over other countries in reaping the benefits from the green transition. It is worth pointing out that the transport sector is central to the European Green Deal and to the investments financed by the NextGenerationEU plan: this sector is responsible for about one quarter of the EU’s greenhouse gas emissions, and its emissions have to be reduced by 90 per cent by 2050 in order to achieve climate neutrality.

However, in order to fully exploit Italy’s potential advantage, it is crucial to accelerate innovation as a whole and to strengthen Italy’s position in the main industrial sectors linked to ecological transition and sustainable mobility.

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[6] Germany and the United Kingdom are also particularly specialized in the transport sector.

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16. THINKING THE GREEN TRANSITION: EVIDENCE FROM THE AUTO INDUSTRY

Andrea Orame and Daniele Pianeselli *

Classification of JEL: G34, L62, O13, O3

Keywords: automotive, electric car, green transition, technology change, mergers and acquisitions, innovation and patents.

Introduction. — The car industry is one of the most important in Europe: in 2015, it accounted for more than 12 per cent of the value added of the euro-area manufacturing sector. At the same time, road transport contributes 24 per cent of carbon dioxide emissions into the atmosphere, the main cause of global warming and of its adverse effects on human activity.[1] The year 2015 marked a key moment for the European car industry. On 18 September 2015, the American Environmental Protection Agency (EPA) notified Volkswagen AG, Audi AG, and Volkswagen Group of America of their breach of polluting emissions standards, because of a systematic tampering with the group's diesel cars in order to falsify emission tests.[2] This event, known as Dieselgate, brought about the obsolescence of the diesel engine. Less than three months later, on December 13 2015, the strict criteria set in the Paris Agreement for fighting against climate change made the electric car, a technology that was not yet fully mature, one of the few possible alternatives to diesel technology for car manufacturers. Subsequently, the interest of the general public in the electric car has increased sharply — as can also be seen in the growing searches for information on the web (Figure 16.1) — and European legislation has implemented the agreements signed in Paris, making the terms of the transition to the electric car even more stringent. It is in fact in the aftermath of 2015 that the share of electric cars[3] over the total number of registered cars has increased significantly in Europe, from 2.9 per cent in 2015 to 23.5 per cent in 2020, with a concurrent decline in the share of diesel cars (Figure 16.2).

* Bank of Italy

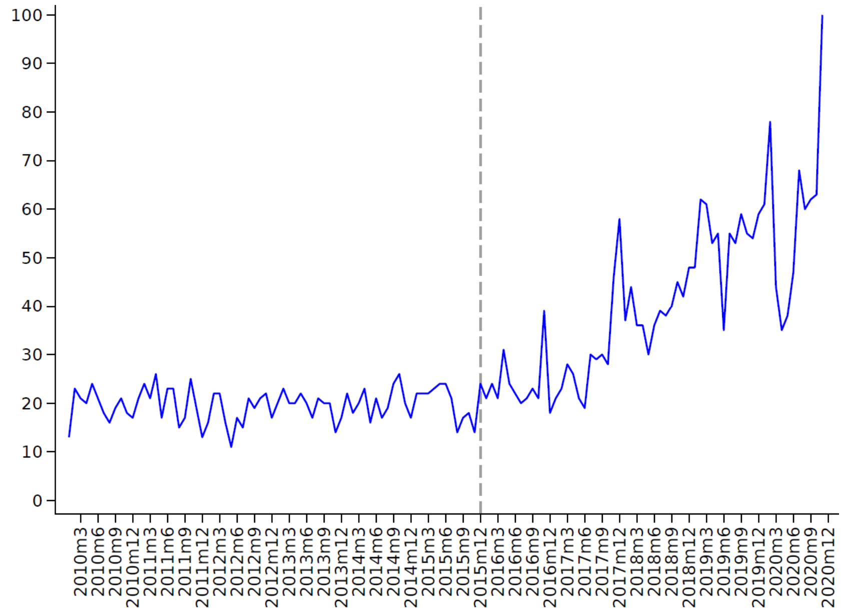
[1] See the Annual European Union greenhouse gas inventory 1990–2015 and inventory report 2017 of the European Environment Agency.

[2] https://www.epa.gov/sites/default/files/2015-10/documents/vw-nov-caa-09-18-15.pdf

[3] Fully electric or hybrid.

Figure 16.1 Google searches: 'electric car'

(index)

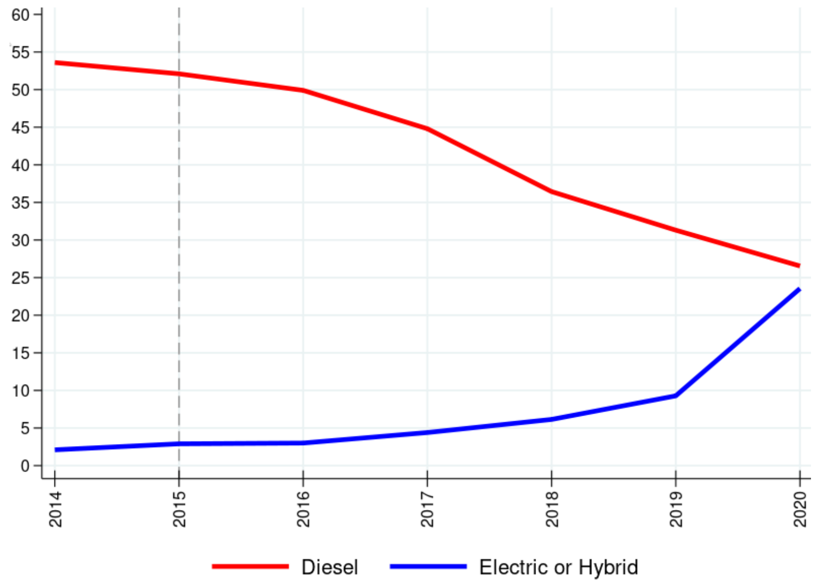


Note: Monthly data normalized to 100 in the month of maximum research interest between 2010 and 2020. Geographical area of reference: 'world'.

Source: Google Trends.

Figure 16.2 Share of total car registrations

(percentage values)



Note: EU15.

Source: Our calculations based on ACEA data.

The year 2015 was a turning point for the car industry, a shock of historical importance.[4] The need to recombine existing technologies in a short time and the increased complexity of the

[4] Regarding doubts about the ability of certain sectors to respond to particular shocks, see, for example, Jensen (1993). On the reaction to shocks in the car industry, see Bresnahan and Ramey (1993).

electric car are demanding extraordinary measures from manufacturers.[5] The traditional diesel specialization of the Italian supply chain and the innovative gap in the production system of our country (Bugamelli *et al.*, 2012) are elements that could negatively affect the transition to the electric car of the Italian auto industry, to the benefit of its European competitors.

Two possible roads. — The economic literature identifies two possible strategies, linked but in any case distinct, as possible responses to important technological shocks. On the one hand, companies can step up R&D to increase innovative output and secure a competitive advantage over their competitors (Lerner and Zhu, 2007; Arora *et al*., 2008). Among the main factors capable of promoting this strategy, the literature identifies the wealth of knowledge and the results of past innovative activity ('path-dependency'). Those factors can segment the automotive sector into firms that are able to operate mainly with 'clean' technologies and those who remain specialized in 'dirty' technologies.[6] On the other hand, it is possible to acquire new skills and technologies directly on the market through mergers and acquisitions (M&As) with other companies.[7] Some works highlight how M&A operations tend to cluster in certain periods and sectors, indicating their greater likelihood of success during major transition phases (Mitchell and Mulherin, 1996; Andrade and Stafford, 2004). In addition, a faster transition, thanks to the acquisition of skills and technologies that are otherwise difficult to develop internally, can provide immediate advantages over direct competitors. However, in order to make effective use of this strategy, the literature identifies an adequate absorptive capacity as a precondition, i.e. a sufficient level of expertise to enable companies to identify complementary technologies on the market, to decode them and to incorporate them into the company's know-how, once it has been formally acquired (Cohen and Levin, 1989; Griffith *et al*., 2004). Our work (Orame and Pianeselli, 2022) therefore aims to compare the strategies adopted by Italian companies in the transition towards the production of low-emission vehicles with those adopted in other countries (European Union and Great Britain) by interpreting the results in light of the literature to which it intends to contribute.

The data. —By using Bureau van Dijk's ORBIS dataset, it was possible to create a sample of some 6,000 companies operating in the European automotive industry between 2013 and 2018 using their annual financial statements.[8] To evaluate their innovative activity, we used the PATSTAT database of the European Patent Office (EPO), associating the companies in our sample with the information on the assignees of the patents. This unique assignment was made by developing a fuzzy matching algorithm based on various measures of similarity between the information concerning the companies in our sample and those relating to the assignees of the patents.[9] Finally, the mergers and acquisitions of these companies between 2013 and 2018 were also analysed. For this purpose, the information in the ZEPHYR dataset of Bureau van Dijk was matched with our sample of firms. The granular dataset has also made it possible, on the one hand, to investigate the nature of patent applications, thus being able to distinguish patents directly or indirectly oriented towards the reduction of pollutants[10] and, on the other, to assess the technological content of the sector to which the companies acquired in M&A operations belonged.[11]

[5] Confirming the increased technological complexity of electric vehicles, a recent article in the *Financial Times* states that in an electric car, there are about 100 million lines of programming code, while in an airliner there are 'only' 14 million.

[6] We refer to technologies that make it possible or not to produce cars that can have a limited impact on the environment. See Aghion *et al.* (2016) and Malerba (1992).

[7] Cefis and Marsili (2015) note how M&As can help a company to move from being non-innovative to becoming an effective innovator, i.e. to overcome the 'innovation threshold'.

[8] Closed sample of companies producing car and car components (NACE 29) with their headquarters in the EU27 or the United Kingdom.

[9] Our algorithm extends the methodology described in Lotti and Marin to European level (2013).

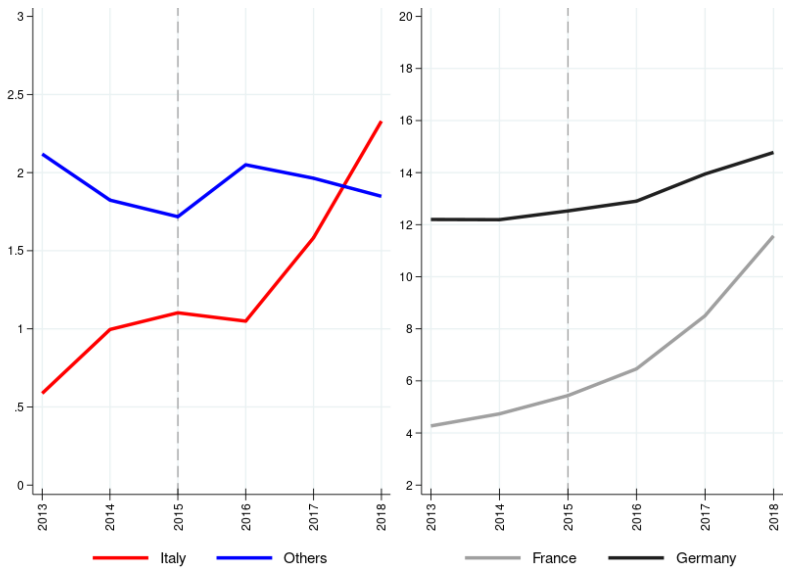
[10] Using the Cooperative Patent Classification (CPC) scheme, it was possible to identify patents whose technologies are dedicated to adaptation to climate change (class Y02A) and mitigation of its effects (classes Y02E, Y02P, Y02T, Y04S).

[11] In particular, we kept track of EUROSTAT 'high-technology' and 'medium-high technology' firms in the manufacturing sector and 'high-tech knowledge-intensive' firms in the service sector.

The results. — Between 2013 and 2018, the patent activity of Italian companies in the car industry increased sharply, particularly after 2015, when Italian companies stepped up their propensity to patent, indicating greater efforts in R&D activity. However, this increase was not sufficient to close the existing gap with France and Germany, the main comparison countries (Figure 16.3). Similar indications emerge by focusing the analysis on those patents that are directly or indirectly oriented to the reduction of polluting emissions.

Figure 16.3 Patents

(indices)

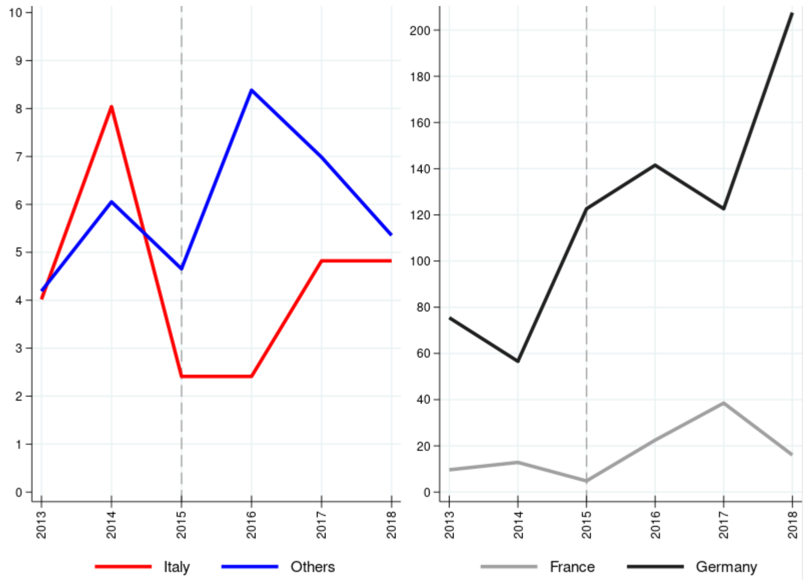


Note: Number of patent applications over total assets in billions of euros. 'Others' represents the average of the European Union and Great Britain, excluding Italy, France and Germany.

Source: PATSTAT.

Figure 16.4 Mergers and acquisitions (M&As)

(indices)



Note: Number of M&As out of total enterprises (thousands). 'Others' represents the average of the European Union and Great Britain, excluding Italy, France and Germany.

Source: Zephyr — Bureau van Dijk.

Looking at the acquisition of new skills on the market, Italian companies resorted systematically less to M&A operations than their European peers (Figure 16.4). Similar results also emerge by focusing the analysis on mergers and acquisitions involving at least one company operating in a high-tech sector.

The evidence presented so far is descriptive. First, Italian companies could have characteristics that make them systematically different from those in Europe, thus influencing aggregate trends (size or the habit of protecting the results of innovative activity with patents). Moreover, in the years after 2015, companies may seem to have differed first in their propensity to patent or make M&A operations (extensive margin), and then in the number of patents or M&As (intensive margin). While the extensive margin describes the (binary) choice of whether or not to innovate within the enterprise or to acquire skills and technologies externally, intensive margin decisions determine the overall level of innovation and acquisitions, i.e. how much innovation to make or how many enterprises to acquire. In order to take account of these differences, we used different econometric models that are able to address such issues.[12]

The initial findings are confirmed in the estimated coefficients. With regard to the extensive margin of innovation activity, with other factors holding constant, Italian companies have further increased their propensity to patent in the years after 2015, both compared with the past and compared with other European companies in the sector (+ 12 per cent). However, they did not close the existing gap with the main competitors. Nevertheless, by analysing patents directly aimed at reducing polluting emissions, the results lose their statistical significance, signalling how becoming an innovator in a new and complex field such as the green one can be more

[12] In addition to the classic linear models, the extensive margins used probit models, fixed-effect logits, and probit models that use Heckman's correction for distorted samples. For intensive margins, Poisson models, fixed-effect Poisson models and Poisson models using Heckman's correction for distorted samples were used.

difficult. The analysis of the intensive margin then offers further insights. The number of patents (green and non-green) filed by Italian innovative companies after 2015 is not statistically different from that of other European companies; instead, there is a sharp increase in the intensity of innovation when only considering patents that incorporate technologies to mitigate the effects of climate change. The results therefore show that the cohort of innovative Italian companies in the automotive sector, following the shock of 2015, gave priority to innovative activity in 'green' technologies. As regards M&A deals, however, in the years after 2015, Italian companies were less active, other things being equal, compared with both their past and other European companies in the sector (-15 per cent). The possibilities for multiple acquisitions by Italian companies virtually disappeared after 2015. In comparison with their European competitors, the reduction was around 70 per cent (the most conservative estimate), with even more severe effects in the case of acquisitions of high-tech companies. The Italian automobile sector has therefore remained virtually excluded from the strong wave of acquisitions fuelled by the intense demand for green technologies. Several robustness analyses have confirmed the validity of these results. Even excluding the main car manufacturers from the analysis and splitting the sample between small and large companies, the analyses confirm the hypothesis of a different trajectory of Italian companies in their response to the shock that hit the car sector in 2015.

Conclusions. — The literature provides useful elements for the interpretation of the results described above. Cefis and Marsili (2015) show that M&As can help companies cross the threshold that distinguishes non-innovators, or occasional innovators, from persistent innovators, i.e. going over the innovation threshold. However, Hagedoorne and Wang (2012) indicate that to take this step effectively, it is also necessary to have already developed a minimum set of knowledge to recognize and assimilate new skills, i.e. to have developed an absorptive capacity internally. Aghion *et al*. (2016), in a specific study on the automotive sector, also argue that today's innovative capacity in 'green' technology depends closely on what was developed in the past. The data seem to suggest that Italian companies are now trying to develop the internal skills needed for the transition to the electric car, while the rest of Europe seems on average to already be at the next step. This evidence is even more important in light of the recent approval by the European Parliament of the ban on the sale of cars with endothermic engines from 2035.[13] If the lag in adapting today's new production technologies is not recovered in the coming years, it could jeopardize tomorrow's market share for Italian companies in favour of their competitors.

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[13] On 8 June 2022, the European Parliament voted in favour of the adoption of the European Commission's "fit for 55" plan. However, in order to enter into force, the Commission's legislative proposal will require ratification by the Member States of the Union in the coming months.

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17. CREDIT SUPPLY AND SUSTAINABLE INVESTMENT

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Classification of JEL: G32; Q54; Q55

Keywords: Climate finance, financial intermediation, credit supply.

Introduction. — To mitigate the effects of climate change, the European Union has set an ambitious goal of zeroing its net CO_2 emissions by 2050.To this end, many companies will need to start making significant investments to reduce their ecological footprint, replacing emission-intensive technologies with less environmentally impactful ones. According to the most recent Investment Survey conducted by the European Investment Bank, about half of European companies had invested in energy efficiency technologies in 2020, ten percentage points higher than in the previous year. However, the same survey indicates the existence of financial constraints that represent a significant obstacle to sustainable (or 'green' investment) for more than one quarter of companies.

The availability of external financing sources plays an important role in the investment decisions of companies (see for example Peek and Rosengren, 2000; Campello *et al.*, 2010; Ferrando *et al*., 2019); in particular, changes in bank credit supply, the main source of financing for Italian companies, have a significant impact on companies' capital accumulation choices, especially during recessions (Gaiotti, 2013; Cingano *et al*., 2016).

In our paper (Accetturo *et al.*, 2022), we address this topic by investigating the role of the availability of funding for the ecological transition. We analyse in particular the impact of changes in bank credit supply on sustainable investments by companies, an issue that has not been investigated so far in the economic literature.[1]

The relationship between credit availability and green investment is a priori ambiguous. Green investments are not necessarily aimed at maximizing the profit of companies, as they are driven by the need to reduce their negative externalities to the environment. With this in mind, the availability of credit could have a limited effect on the choice to make this type of investment. However, in recent years, as a result of ongoing climate change and consequent changes in consumer environmental preferences, entrepreneurs seem to have incorporated the environmental impacts of their business into their companies' objective functions (Hart and Zingales, 2017; Pàstor *et al*., 2021). The purpose of this process is also to avoid reputational damage that could harm the business as a whole; the choice to make green investments could prove economically rational and therefore also subject to the availability of financial resources. In this context, an empirical investigation of the relationship between bank credit and sustainable investment is essential.

The data. — Balance sheet data — which are typically used to study the determinants of capital accumulation — do not contain details on the types of firms' investments. Hence, in order to distinguish their level of environmental sustainability, a detailed analysis of the supplementary notes to the financial statements in the Infocamere database was carried out. We implemented a textual analysis algorithm based on a dictionary of words that identify

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[1] More generally, the literature on sustainable finance has seen significant growth in recent years focusing, in particular, on the risks of climate change for the financial system (see Giglio *et al.* (2021) for a review on the topic) and on the impact of sustainable policies by banks on financing policies (Degryse *et al.* (2020) and Kacperczyk and Peydró (2021) among others).

environmentally sustainable activities (such as photovoltaic, cogeneration, renewable energy, etc.) in the commentary notes to investment activity (Table 17.1). Business investments were therefore referred to as 'green' when, in the year in which they were undertaken, one of the dictionary words appeared in the comment note. Our green investment indicator is confirmed in the ISTAT permanent census data: at region-sector level, the measure is in fact positively correlated with the percentage of companies that have made sustainable investments. The sample consists of about 30,000 companies, mainly small and medium-sized, for which we combine Cerved Group balance sheet data and information on credit reports from the Central Credit Register, for the period between 2015 and 2019, for a total of 110,000 observations.

Table 17.1 Examples of keywords identifying environmentally sustainable activities

#	Text
1	Spese di progettazione per l'ampliamento delle celle frigo e l'installazione di un **impianto fotovoltaico** (€ 5.148) e interventi generici di manutenzione straordinaria (€ 24.800), presso il settore del Mattatoio.
2	Attività di sviluppo precompetitivo finalizzate all'individuazione di nuove soluzioni tecniche e tecnologiche per la messa a punto di soluzioni innovative di packaging totalmente riciclabile e provenienti da **fonti ecosostenibili**.
3	Tali investimenti hanno valenza a **fini ambientali** in quanto lo scopo dell'investimento è di produrre energia elettrica mediante impianto alimentato da **fonte rinnovabile solare** e nel contempo di ridurre la domanda di energia da altre fonti tradizionali.
4	I modesti incrementi dell'esercizio sono riferiti all'aggiornamento della certificazione SOA e ad oneri connessi con la ricerca nel campo delle **fonti rinnovabili**.
5	Si ricorda che all'interno della categoria Impianti e macchinariâ sono compresi gli **investimenti ambientali** realizzati dalla società negli esercizi precedenti, costituiti da **impianti fotovoltaici** destinati alla produzione di energia elettrica da **fonti rinnovabili** da impiegare nel ciclo produttivo.
6	Le aliquote di ammortamento mediamente applicate sono le seguenti: FABBRICATI 3% MOBILI E ATTREZZATURE 10% MACCHINE D'UFFICIO 12% ATTREZZATURA GENERICA 12,5% ATTREZZATURA SPECIFICA 12,5% BIANCHERIA E LANERIA 20% **IMPIANTO FOTOVOLTAICO** 15% IMPIANTO ANTINCENDIO 10% IMPIANTO DI RISCALDAMENTO 12%

Note: The Table shows an extract of comments on the items relating to tangible and intangible assets contained in the notes to the financial statements of companies. Bold words belong to the dictionary used to identify green investments.

Source: Authors' analysis based on Infocamere data.

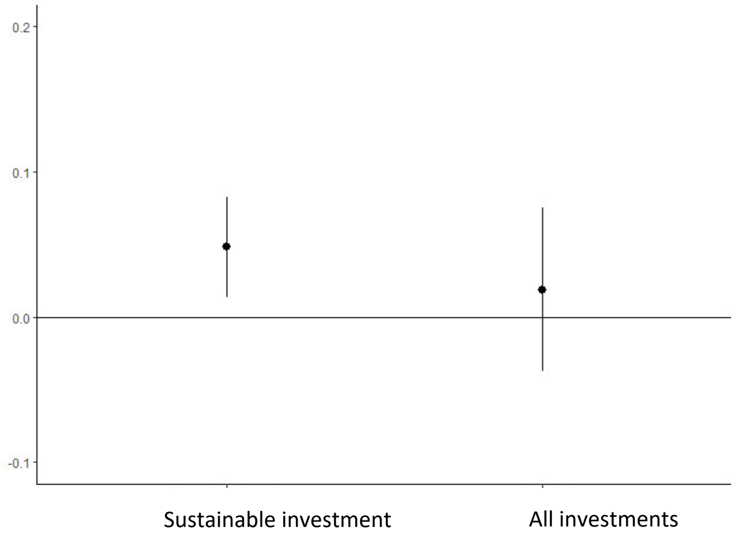
The role of bank credit. — In empirically analysing the relationship between bank credit availability and green investment, it is crucial to take into account several issues of endogeneity. A positive correlation between external financing and capital accumulation could depend not only on supply factors (the increased availability of financing leads to a rise in the propensity to invest) but also on demand factors (the increase in the propensity to invest by companies leads to a rise in the financing required by the banking system). It is also possible that companies that decide to undertake sustainable investments are structurally different from others and characterized, for example, by higher productivity and better managerial practices; these characteristics, in turn, affect their creditworthiness and therefore their ability to access bank loans. In order to solve these problems empirically, we have considered exogenous shocks to the supply of bank credit, which therefore do not depend on the characteristics of companies and their ex ante propensity to invest in sustainable technologies. To this end, we have used the instrumental variable strategy proposed by Berton *et al. (2018*) and Greenstone *et al. (2020*). Specifically, we have constructed an index that uses changes over time in the propensity of individual banks to offer credit net of the demand for loans they face; this index is used as an instrument for the bank loans actually received by companies.

The results show that green investments respond to the supply of credit in an economically significant way: a 10 per cent increase in credit determines a 0.5 percentage point increase in the likelihood of a company undertaking a sustainable investment (6 per cent on average). In relative terms, a change of one standard deviation in credit supply is associated with a change of approximately 14 per cent in the standard deviation of the probability of investing in green technologies. This relationship appears to be stronger than that between the availability of loans and generic investments (therefore not necessarily 'green'; Figure 17.1).

This difference results from the fact that green investments require companies to have greater financial resources, thus making them more reliant on external financing than ordinary ones. Using a financial constraint indicator known in the literature as the 'SA' index (Hadlock and Pierce, 2010), the relationship between credit supply and sustainable investment is stronger for the most constrained companies on the credit market, typically smaller and younger ones.

Figure 17.1 Sustainable investment and credit provision

(estimated elasticities)



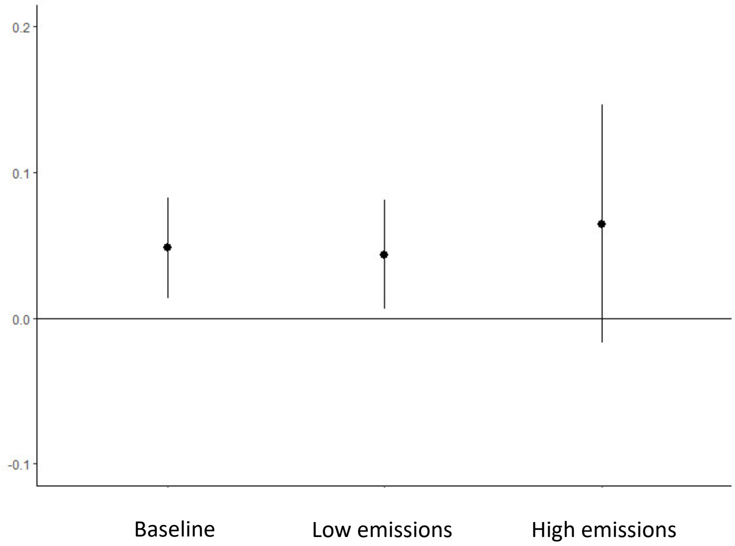
Note: The figure represents the elasticity to credit supply of sustainable investments and of all investments. Error bars report a 95 per cent confidence interval.

Source: Authors' calculations based on Cerved Group and Central Credit Register data.

The role of the most polluting activities. — The positive relationship between bank credit supply and green investment could also depend on their risk-adjusted return (Delis *et al.*, 2018). For example, the choice to adopt more sustainable technology could greatly increase the likelihood of survival or profitability for particularly polluting companies, especially at a time when the carbon footprint of production activities needs to be significantly reduced. The banking system could therefore find it profitable to finance these activities. However, our results do not indicate a statistically significant difference in the elasticity of the green investment propensity to provide credit to more or less polluting companies (Figure 17.2).

Figure 17.2 Green investment and credit offering
The role of the most polluting activities

(estimated elasticities)



Note: The figure represents the elasticity of sustainable investments to credit supply for different greenhouse gas emission intensities. Error bars report a 95 per cent confidence interval.

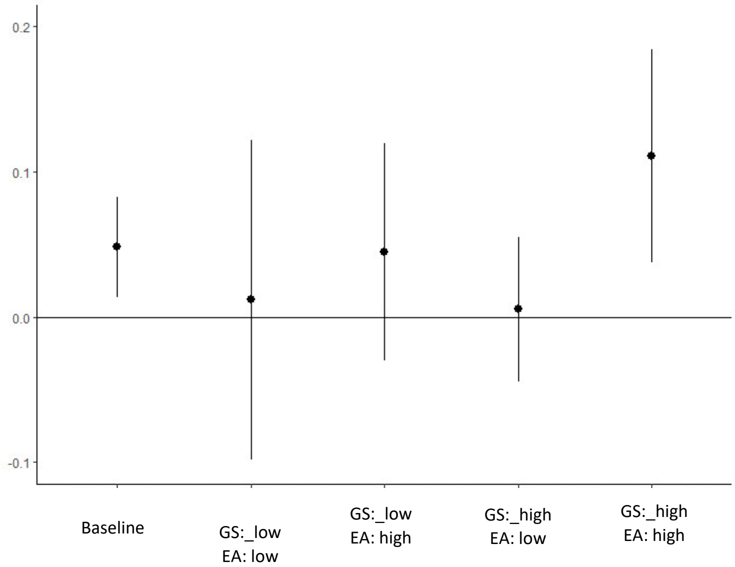
Sources: Authors' calculations based on data from Cerved Group, the Central Credit Register and the World Input Output Database.

The role of environmental preferences. — As mentioned above, environmental issues can be incorporated by entrepreneurs into their investment choices, thus reducing the externality typically associated with sustainable investments (Krueger *et al.*, 2020; Choi *et al.*, 2020; Briere and Ramelli, 2021). To analyse this channel, we measure environmental preferences at regional level using the share of the population that places greater weight on environmental protection, according to the European Value Study of 2017 and Google searches for 'climate change'. The findings indicate that the awareness of environmental risks plays an important role: the elasticity of green investments to the supply of credit is in fact higher where the importance attached to environmental protection is greater.

The role of public subsidies. — Another potential driver of green investment is public subsidies, the availability of which can be measured at regional level based on the information in the National State Aid Register. We show that only companies located in regions with a high level of subsidies show a statistically significant coefficient to make 'green' investments when their credit supply increases. When the environmental awareness of the local population is included in the analysis, we find that only companies located in regions belonging to both groups with a high incidence of green incentives and high environmental awareness are more likely to make sustainable investments if the availability of credit increases (Figure 17.3). These results suggest a complementarity between bank credit, public subsidies and population preferences in stimulating sustainable investment.

Figure 17.3 Green investment and credit supply
The role of public subsidies

(estimated elasticities)



Note: The figure represents the elasticity of sustainable investments compared with the provision of credit for different combinations of green subsidies (GS) and environmental awareness (EA). Error bars report a 95 per cent confidence interval.

Source: Authors' calculations based on data from Cerved Group, the Central Credit Register, Google and the National State Aid Register.

Conclusions. — Our results show that credit supply increases the propensity of companies to invest in green technologies. This impact is greater in areas where awareness of environmental issues is stronger and the involvement of the public operator in financing the ecological transition is greater. Two major implications for economic policy can be identified. The first refers to the role of the banking system that channels, in a 'bank-centric' country such as Italy, a significant part of the funding needed for green investments. Sudden reductions in credit supply, as happened in the past during the great recession and the sovereign debt crisis, can therefore have negative effects, not only on the accumulation of inputs (capital and labour, see Cingano *et al., 2016* and Berton *et al.,* 2018) but also on the ability of companies to adopt sustainable technologies. The second reflects the role of the environmental awareness of the population and (presumably, as a reflection) of local administrators. Bank credit's ability to increase its propensity to make sustainable investments is only positive where population preferences favour the inclusion of environmental sustainability in the objective function of businesses. In this sense, policies aimed at promoting pro-social behaviour of citizens and entrepreneurs could further accelerate the ongoing transition.

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