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Research article

The public finance response to floods of local governments in Italy☆

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ABSTRACT

This paper aims to empirically test the dynamics of budget outcomes of Italian municipalities in the aftermath of floods by accounting for heterogeneous levels of resilience and vulnerability to natural disasters. Our findings are based on a dynamic difference-in-differences model after propensity score matching. They point to substantial impacts in terms of increased capital expenditure and revenues from transfers, which depend on the degree of resilience and vulnerability. Through our analysis, we account for multiple aspects of risk to support policy decisions related to both ex-ante and ex-post disaster occurrence management.

1. Introduction

Over the past 50 years, climate-induced disasters have accounted for about 50% of worldwide disasters recorded on the EM-DAT database and over 70% of all economic losses, which have been estimated at about 3.7 trillion dollars (WMO, 2021). Even though scholars still do not have the smoking gun that indicates the role of human activity in the increasing global occurrence of small-scale extreme weather events, a growing number of studies points to a causal link between climate change and such events, especially extreme rainfalls that turn into flooding (WMO, 2021; Kirchmeier-Young and Zhang, 2020).

Today, it is well recognised that climate change (CC) represents one of the most urgent and fundamental problems that public and private actors must face to reduce the number of victims and injured from extreme climate-induced events as well as their associated economic costs. CC is likely to exert a high influence on future extreme natural events, which will damage local areas and communities. However, the amount of damage depends on the combination of the actual occurrence of hazards (probability and magnitude) and the inherent socioeconomic characteristics of the affected areas, which can be proxied with the multifaceted concepts of resilience, vulnerability and exposure (Marin et al., 2021). For this reason, it would be more correct to talk about "socio-natural hazards" instead of "natural disasters" (Hallegatte, 2014a).

The damage arising from an extreme event depends not only on physical factors but also on the ability of local communities to be prepared for, face, mitigate and respond to the event. Furthermore, the occurrence of natural disasters is initially faced by local public institutions that assess the risk and manage first emergency response, as well as search and rescue activities. These capabilities are connected with their level of proactivity; underprepared areas are the most damaged ones (Breckner et al., 2016; Chan et al., 2016; Kahn, 2005; Ostadtaghizadeh et al., 2016; Parsons et al., 2016; Raschky, 2008). Differences in the shock adaptation capacity may also vary according to

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spatial and geographical characteristics, such as an area's degree of rurality.[2] Therefore, even though national and supranational entities are in charge of urgent actions to cope with CC impacts, local governments should rethink their climate risk assessment framework. This framework should deal with mitigation and adaptation activities aimed at preventing the effects that a changed climate might have on local territories from an ex-ante perspective and helping post-disaster recovery from an ex-post perspective.

However, most of the mitigation and adaptation activities are also related to healthy local public finance conditions and even though the literature has highlighted the impact of extreme climate events on public finance (e.g., Heipertz and Nickel, 2008; Lis and Nickel, 2010; Phaup and Kirschner, 2010), few studies have analysed the effect of selected impacts on government budgets (e.g., Bachner and Bednar-Friedl, 2019). Little attention has been paid to the shocks generated by extreme climate events in terms of local public financing capabilities and fiscal policies. We argue that the areas that are more susceptible to suffering from a changed climate will necessarily drain resources from the local public budget to prevent and mitigate risks and recover after a shock affects them. This might be detrimental in the case of "recurrent" disasters, such as floods. Over the past decades, due to global warming, floods have captured higher attention as their frequency, severity and intensity are constantly rising worldwide (EEA, 2010; IPCC, 2022). This hazard has underlined how major urban centres that have not implemented an adequate risk assessment framework are the most damaged areas (Benson and Clay, 2004). The EEA has estimated about 446 billion euros of economic losses caused by climate-related extreme events between 1980 and 2019.

Given these premises, our work aims to empirically test the dynamics of local governments' budgetary outcomes in the aftermath of floods in a country that is highly vulnerable to such events – Italy (Faiella and Natoli, 2018). Italy is very susceptible to hydrogeological risks due to its geological, morphological and hydrographic characteristics. Moreover, illegal building, overbuilding and urbanisation represent other important drivers of risk. According to ISPRA (2021), almost 94% of Italian municipalities show high hydrogeological risk. Specifically, 7 million people, 13.4% of buildings and 84,000 cultural heritage sites are at flood risk. Moreover, according to the EM-DAT database, since the end of the 1930s, Italy has been one of the most damaged countries in terms of deaths, injured/affected people and damages due to extreme floods (54 disasters are reported). Main extreme events concern the entire Po River Basin; northern Italian regions, such as Emilia Romagna, Tuscany, Veneto, Lombardy and Liguria, are highly affected by floods. In 1951, the area of Polesine, the territory located between the lower course of the Adige and Po rivers up to the Adriatic Sea, had suffered the most dangerous flood of the last century: 239 deaths and around 3 million of damages have been recorded (EM-DAT). Overall, a 2012 study of ANCE/CRESME, 2012 estimated that 61.5 billion euros of public funds were provided by the Italian government for recovery after hydrogeological events between 1944 and 2012 (about 1 billion euros per year), and the estimated costs are even higher (Zampetti et al., 2012). Italy is also the country with the largest absolute uninsured losses in the European Union (Amadio et al., 2019; Donnini et al., 2020; EEA, 2016). Therefore, quite often, the Italian government has funded reconstruction activities by imposing new taxes (e.g., excise duty on oil in 2009 after the L'Aquila earthquake; CNI, 2016). This is an issue for a country highly affected by several hazards, and it casts a shadow on the will of the Italian government to setup prevention and mitigation strategies. Therefore, we consider different levels of socioeconomic resilience and vulnerability among Italian municipalities to infer whether their capacity to cope with disasters is affected by their socioeconomic characteristics. Understanding a municipality's fiscal response to disasters is fundamental given that some previous decisions about the allocation of financial resources and taxation can be changed (Benson and Clay, 2004; Taulbee, 2019; Miao et al., 2020). On the expenditures side, planned investments and ongoing projects might be postponed or abandoned, while new projects and expenditures might be needed to cope with emergencies and post-event reconstruction. On the revenues side, local taxation provisions are generally subject to negative (tax cuts for post-event recovery or reduced tax base) or positive (additional transfers and taxation to cope with new expenditures) changes (Benson and Clay, 2004).

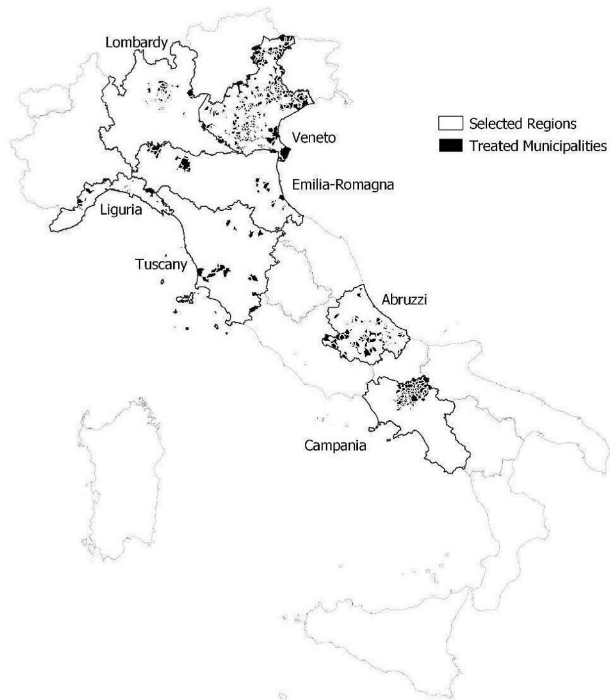
Currently, there are few studies on the impact of extreme climate events on the financial and budgetary outcomes of public institutions, especially at the subnational level (Faiella and Natoli, 2018). The literature focuses on analysing the consequences of extreme hazards on fiscal policies at the country level, with mixed results (Heipertz and Nickel, 2008; Lis and Nickel, 2010; Noy and Nualsri, 2011; Melecky and Raddatz, 2014; Miao et al., 2018). The findings of this literature depend on the different aspects that are considered (e.g., event severity, country and government characteristics, model assumptions and variables). For example, Noy and Nualsri (2011) used a sample of 42 developed and developing countries in the 1990–2005 period. In the case of developed countries, they found that natural disasters have a negative effect on revenues and cash surplus; they also recorded an increase in government payments and outstanding debt. In the case of developing countries, all fiscal variables are negatively affected by extreme events, except cash surplus. Similarly, Lis and Nickel (2010) and Melecky and Raddatz (2014) found that less advanced nations face a larger effect on public nominal budget balances in the aftermath of extreme events compared to advanced economies.

However, few studies have analysed the fiscal response in the aftermath of extreme climate events at the subnational level. Miao et al. (2020) estimated the dynamic effects of several natural disasters on government finance in 30 Chinese provinces in the period 1994–2014. Their results suggest that expenditures and intergovernmental transfers increase in the aftermath of the event and then gradually decrease over time, while a limited effect on revenues was found. Jerch et al. (2021) and Taulbee (2019) analysed the relationship between natural disasters and local (municipal/county) government finances in the United States. Jerch et al. (2021) found that hurricane exposure causes a decline in revenues and expenditures in the long run as a result of the fall in local tax revenues. In the short run, the decrease in revenues is mitigated by incoming intergovernmental transfers. Taulbee (2019) examined the impact of extreme climate events (as declared by the Federal Emergency Management Agency) on the fiscal spending and revenues of counties in the state of Kentucky between 2007 and 2017. He found a significant increase in intergovernmental transfers and a decrease in incoming taxes, while no significant change in expenditures per capita.

Considering the existing literature, we constrain our analysis to floods affecting municipalities in nine Italian NUTS2 regions in the 2013–2016 period. To estimate the impact of floods, we have implemented a dynamic difference-in-differences approach coupled with propensity score matching over a panel of 4185 Italian municipalities with monthly data. Since the amount of loss and the ability to react to extreme climate events also depend on the structural characteristics of each municipality, we have investigated the effects of selected floods on budgetary outcomes by distinguishing between municipalities with high and low resilience and vulnerability. To the best of our knowledge, our work is the first to assess the impact of floods on budget outcomes at the municipal level by also analysing conditions of vulnerability and resilience.

Our results suggest that on average, Italian municipalities react to floods by increasing investments. This effect is not counterbalanced by adjustments in revenues, so substantial imbalances could emerge. Through a deeper analysis of municipal budget breakdowns, we argue that the results greatly depend on the municipalities' degree of resilience

[2] As highlighted by Cutter et al. (2016), economic capital is more relevant to increasing the disaster resilience of urban areas, while social capital is more important in enhancing the resilience of rural areas.



Note: Sardinia and Basilicata are not shown on the map due to the absence of treated municipalities.

Fig. 1. Selected Regions and Treated Municipalities
Note: Sardinia and Basilicata are not shown on the map due to the absence of treated municipalities.

and vulnerability. Specifically, we show that more resilient (and less vulnerable) municipalities are better able to face floods because they can handle greater flows of already available resources without waiting for transfers from other government levels.

2. The general framework for disaster management in Italy

In this article, we focus on a specific policy implemented by the Italian government; that is, the decision by the Italian Council of Ministers on July 28, 2016 to allocate funds for reconstruction interventions linked to 49 flooding events that had national relevance and affected the country's regions over the 2013–2016 period. For all these events, a state of emergency was declared. According to Italian legislation, a state of emergency can be declared after the occurrence or in the imminence of exceptional events, such as extreme natural events (earthquakes, floods, drought and, more recently, the Covid-19 pandemic). This state is strictly regulated by the law and declared by the Council of Ministers in agreement with the governors of the affected regions. The state of emergency allows public authorities to act urgently and with extraordinary powers (i.e., derogating from ordinary legislation). This state lasts one year and can be extended only for an additional 12 months. According to the Italian Civil Protection Department, a state of emergency has been declared in Italy more than 100 times since 2013.

The decision of the Council of Ministers allows for the compensation of costs suffered by private citizens and economic actors (e.g., repairing private buildings and businesses' structures, systems and equipment), as well as for the purchase of stocks of raw materials, semi-finished and finished products that were damaged or destroyed due to the event.

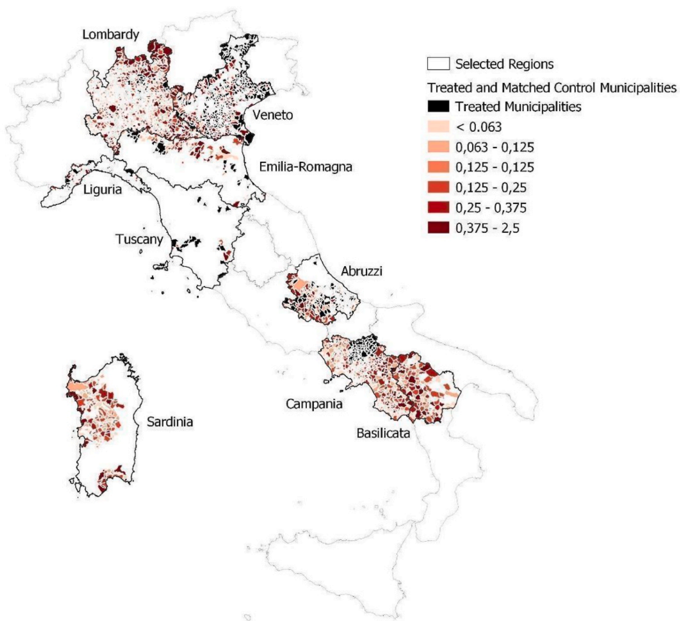
The first set of activities is carried out by the head of the Civil Protection; a regional delegate is then appointed when the emergency phase has ended. The Civil Protection system generally differentiates its activities by type of event and type of operative centre according to the geographical extent of the event. Overall, a hierarchical structure from the municipal to the national level is put in place, with the local mayor acting as the authority responsible for the initial activities of the Civil Protection.

We analysed the Civil Protection and Delegate Commissioner ordinances providing reconstruction funds in a selection of 40 flooding events, and we considered all the municipalities that have received funds.[3] In our empirical analysis, we consider a municipality as treated whenever it receives reconstruction funds. For instance, for the events affecting the Campania region in 2015, we have recognised 152 treated municipalities out of 647. Our starting sample includes 4185 municipalities from nine Italian regions: Abruzzo, Basilicata, Campania, Emilia Romagna, Liguria, Lombardy, Sardinia, Tuscany and Veneto. In this sample, 517 municipalities are classified as treated; their geographical distribution is shown in Fig. 1.

3. Empirical strategy

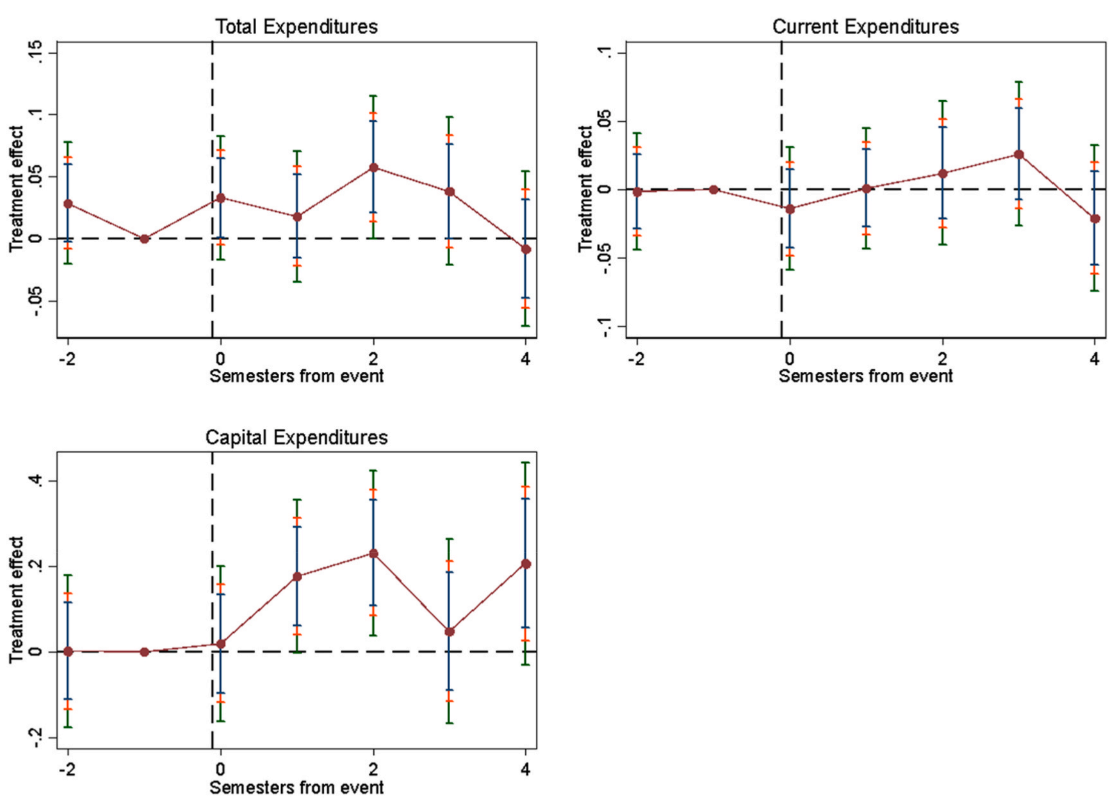
We aim to estimate the effect of floods on municipalities' budgets by means of a dynamic difference-in-differences approach. Even though we do not expect a risk of reverse causality between floods and local governments' budget outcomes, the likelihood that a flood occurs in a specific municipality generating damages that justify the declaration of a state of emergency might be correlated with some attributes that also influence the dynamics of our outcome variables. For example, high-hazard local governments could increase their investments in the maintenance of water-related infrastructure (e.g., reinforcement of levees) before the usual flooding months. Furthermore, the patterns of revenues and/or expenditures of more resilient municipalities are more (or less) smooth than the ones of less resilient ones. For this reason, we decided to identify a priori a proper counterfactual by matching treated municipalities to non-treated ones based on observable characteristics. Specifically, we estimate the propensity score as the predicted probability of being subject to a flood given the pre-treatment observable features of the municipalities and then match each treated municipality

[3] As mentioned at the beginning of section 2, the document of the Italian Council of Ministers identified 49 flooding events, but for nine of them, the estimation of damages is not completed.



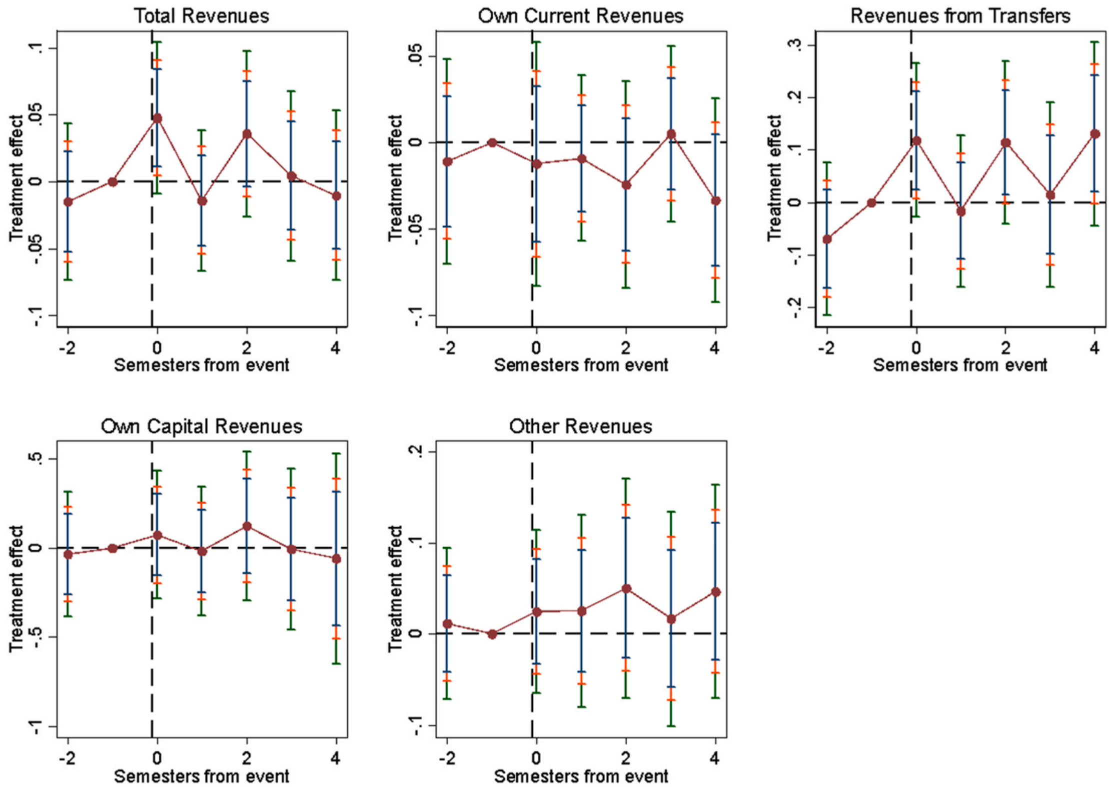
Note: Treated municipalities are filled in black. Matched control municipalities are filled with different shades of red to account for the average contribution (weight) of each municipality to the building of the counterfactual across all different events and outcome variables.

Fig. 2. Treated and Matched Control Municipalities
Note: Treated municipalities are filled in black. Matched control municipalities are filled with different shades of red to account for the average contribution (weight) of each municipality to the building of the counterfactual across all different events and outcome variables. . (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)



Note: Three levels of statistical significance are reported: p-value < 0.1 (blue), p-value < 0.05 (orange), and p-value < 0.01 (green).

Fig. 3. Difference-in-differences Baseline Estimations: Expenditures
Note: Three levels of statistical significance are reported: p-value <0.1 (blue), p-value <0.05 (orange), and p-value <0.01 (green). . (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)



Note: Three levels of statistical significance are reported: p-value < 0.1 (blue), p-value < 0.05 (orange), and p-value < 0.01 (green).

Fig. 4. Difference-in-differences Baseline Estimation: Revenues
Note: Three levels of statistical significance are reported: p-value <0.1 (blue), p-value <0.05 (orange), and p-value <0.01 (green). . (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Propensity score matching variables description.

Variable	Description
Population	Annual resident municipal population on 1st January.
Income	Lagged per capita general income tax IRPEF.
Land Area	Area of a municipality expressed in square kilometres.
Altitude	Metres over sea level of the municipality's city hall.
Island	Dummy equals 1 if part of the territorial area of the municipality overlooks the sea, 0 otherwise.
Coastal	Dummy equals 1 if the municipality area is surrounded by the sea, 0 otherwise.
Resilience	Dummy equals 1 if the resilience of the municipality is above or equal to the third quartile, 0 otherwise.
Vulnerability	Dummy equals 1 if the vulnerability of the municipality is above or equal to the third quartile, 0 otherwise.
Hazard	Share of the total area (in squares kilometres) at hydrogeological risk.

Table 2
Treated municipalities by vulnerability and resilience level.

Resilience/Vulnerability	Low	High	Total
Low	**73**	**201**	**274**
	14.12%	38.88%	53%
High	**182**	**61**	**243**
	35.20%	11.80%	47%
Total	**255**	**262**	**517**
	49.32%	50.68%	100%

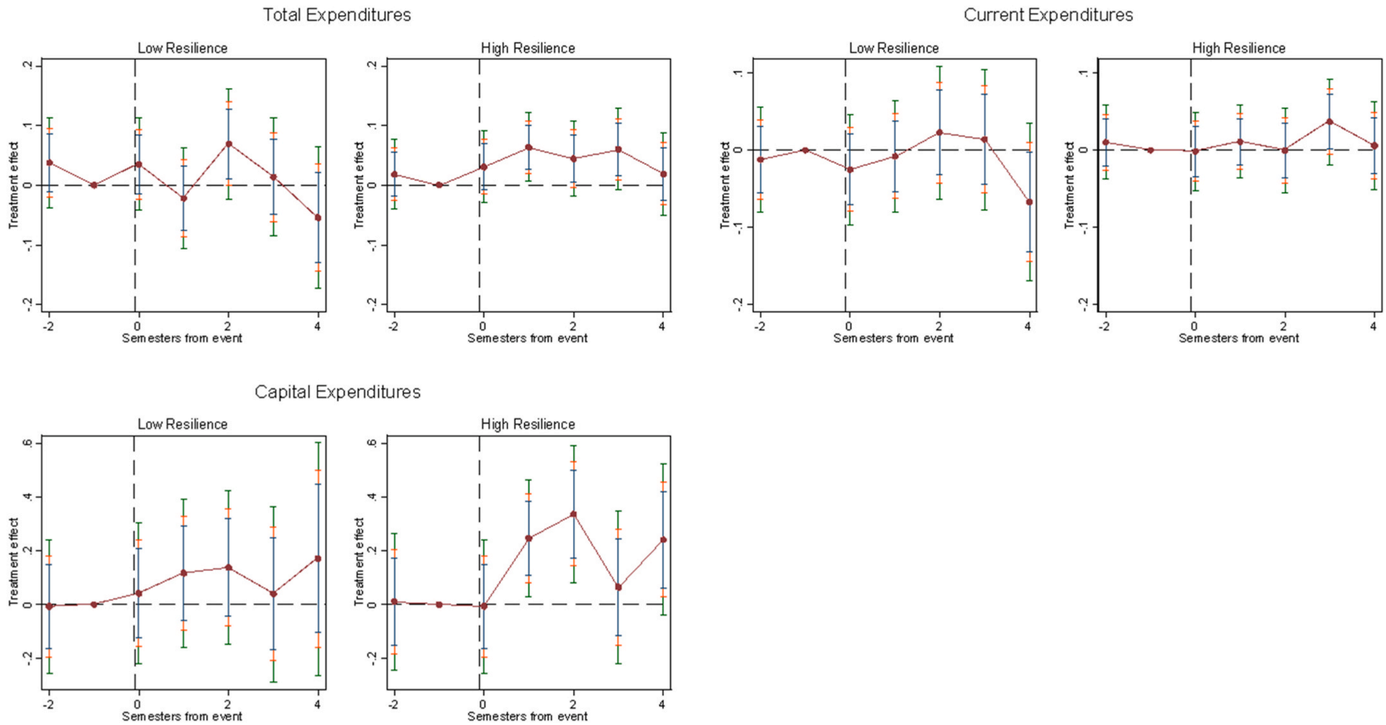
with one (or more) non-treated municipality that has the closest probability of being treated. We then run a dynamic difference-in-differences model on the matched sample.

We exploit the high frequency (monthly) of our data on municipalities' revenues and expenditures to identify the short-term dynamics of the outcome variables in the aftermath of a flood. To limit the issue of seasonality, we group time periods in semesters. Instead of identifying ex-ante an arbitrary month as the beginning of the semesters (e.g., January and July), for each event, we consider the first post-treatment semester to begin in the month when the flood occurred.[4]

The difference-in-differences model is expressed by the following equation:

$$y_{it} = \alpha_i + \tau_t + \gamma_{jt} + \eta_{t-2} Treated_i + \sum\nolimits_{s=0}^{3} \beta_{s+t} Treated_i + \varepsilon_{it} \quad (1)$$

[4] We consider semesters instead of months to account for the seasonality of local governments' expenditures and, especially, revenues. In Italy, local governments collect or receive the bulk of their revenues in December and June (i.e., exactly six months apart). The definition of the beginning of the semester is specific to each treated municipality, depending on when the flood occurs. As for the non-treated (matched) municipalities, we align their time index to the one of the municipalities to which they are matched. For example, imagine that municipality A is subject to a flood in October 2014. Then, according to our propensity score matching procedure, municipalities B and C are matched to municipality A. The time index t for the three municipalities will be set to 0 for the semester October 2014–April 2015 (i.e., the "event semester"). This is a particular application of a staggered difference-in-differences approach that accounts for the recent criticism by Bakar et al. (2020).



Note: Three levels of statistical significance are reported: p-value < 0.1 (blue), p-value < 0.05 (orange), and p-value < 0.01 (green).

Fig. 5. Difference-in-differences Estimations by Resilience Level: Expenditures
Note: Three levels of statistical significance are reported: p-value <0.1 (blue), p-value <0.05 (orange), and p-value <0.01 (green). . (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

where y_{it} is the outcome variable for municipality i, in the t semester; α_i is the municipality fixed effect that accounts (in a flexible way) for all time-invariant characteristics that could be correlated with both the outcome variables and the treatment; τ_t is the semester fixed effect; γ_{jt} is the calendar month dummy for month j, which is allowed to exert a time-varying effect on the outcome variable to account for seasonality. The variable $Treated_i$ is the dummy variable that equals 1 for treated municipalities (as defined in section 3) and 0 for untreated matched municipalities. We assume that the occurrence of a flood in municipality i in a specific month is exogenous (conditional on matching). The two sets of parameters of interest are η_{t-2} and β_{s+t}, which measure, respectively, pre-trends and the average effect for treated municipalities (ATT) on municipalities' budgetary outcomes. The reference semester is the one prior to the event semester. Finally, ε_{it} represents the IID error term.

4. Disaster risk assessment and propensity score matching

Concerning the estimation of the propensity score, the choice of the independent variables is connected with the concept of disaster risk. The risk of a specific climate-related disaster represents the probability of value losses in terms of different aspects, such as damages to economic activity and the well-being of affected areas. The risk is thus a function of the vulnerability, resilience, exposure and hazard of the municipality under analysis (Hallegatte, 2014b; Marin et al., 2021). More formally, the risk for municipality i can be defined as:

$$R_i = f(V_i, Res_i, E_i, H_i) = V_i * (1 - Res_i) * E_i * H_i \quad (2)$$

where V_i corresponds to the vulnerability of municipality i; Res_i is its resilience; E_i represents its exposure, and H_i the flood-specific hazard. If a municipality reaches a high resilience and/or a low vulnerability, mitigation of risks occurs even in presence of high hazard probability and exposure, so the local system is expected to be weakly affected by a flood. Conversely, the risk is likely to be high when the municipality shows low resilience and/or high vulnerability. A detailed explanation of how the indicators are built is found below.

Vulnerability is defined as the set of characteristics of a municipality that can potentially generate harm, independently of the flood risk (Sarewitz et al., 2003). By adopting the same approach as Modica et al. (2019b) and Marin et al. (2021), a composite vulnerability index was built that considers 17 municipality features. Each feature was weighted with the number of times it was used in the literature to measure vulnerability. Each variable was normalised to range between 0 and 1; then, the composite indicator was further normalised to range between 0 (low vulnerability) and 1 (high vulnerability).[5] To consider only relevant (discrete) differences across municipalities, we defined a dummy variable equalling 1 when the municipality has a vulnerability higher than its median value and 0 when this is not the case.

Resilience is the ability of a system to resist, recover, renew and realign after disturbances or shocks (Pimm, 1984; Rose, 2004; Martin, 2012; Zhou and Chen, 2020). As was the case for vulnerability, resilience was measured by starting from a composite index following Modica et al. (2019a) and Marin et al. (2021), which accounts for 13 socioeconomic variables.[6] Aggregation, weighting and normalisation followed the same procedure used for vulnerability, leading to an indicator of resilience ranging from 0 (low resilience) to 1 (high resilience). As for vulnerability, we defined a dummy variable equalling 1 when the resilience of the municipality is higher than its median value and 0 when this is not the case. Please note that vulnerability and resilience have two

[5] For a complete description of the socioeconomic variables of the vulnerability index, see Table A.2 in Appendix A.

[6] For a complete description of the socioeconomic variables of the resilience index, see Table A.3 in Appendix A.

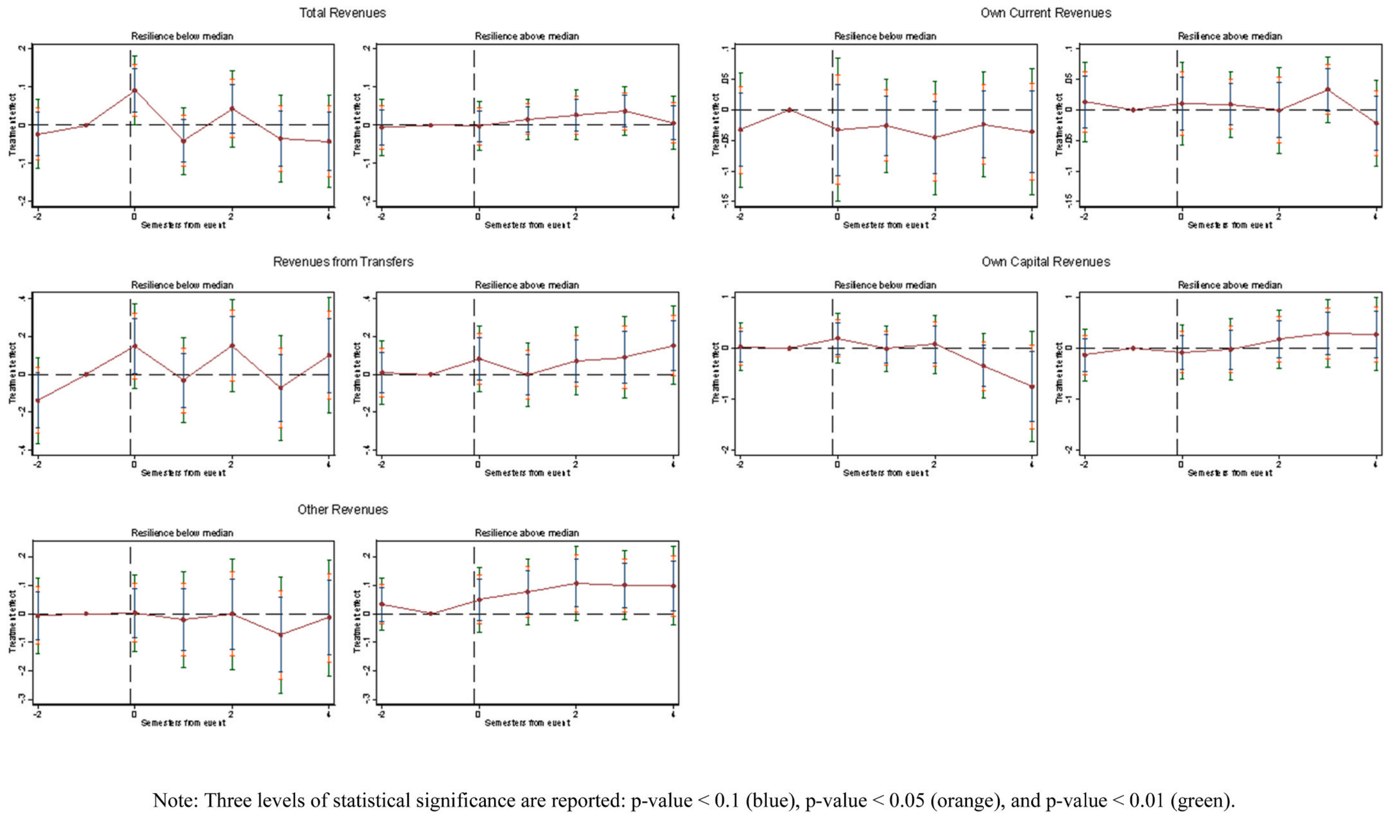


Fig. 6. Difference-in-differences Estimations by Resilience Level: Revenues
Note: Three levels of statistical significance are reported: p-value <0.1 (blue), p-value <0.05 (orange), and p-value <0.01 (green). . (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

different meanings and that their theoretical relation is not univocal; rather, it depends on the framework one adopts (see Cutter et al., 2008 for details). Without entering into this debate, our research framework considers the two concepts as different though interrelated; this gives rise to distinct but quite strongly correlated indicators.

Exposure can be defined as all the assets and the population that may be affected by a hazard (Hallegatte, 2014b). It includes socioeconomic and geophysical features of municipalities. A municipality's exposure was quantified by collecting socioeconomic and geographical data from different sources. From the socioeconomic perspective, population numbers and households' taxable income were considered based on ISTAT and Ministry of Economy and Finance data, respectively.[7] We also took into account the following geographical characteristics of the municipalities: altitude (metres above sea level), coastal/island classification (proximity to the sea or surrounded by the sea) and area (measured in square kilometres).

Hazard is the probability of occurrence of an extreme event that can create perturbations to the economic system. In our study, the hazard refers to floods. The flood probability for each municipality was measured as the share of the total area at risk of flooding (hydrological risk). ISPRA has identified three degrees of hydrological risk: high probability, with a return period of 20–50 years (frequent floods); medium probability, with a return period of 100–200 years (less frequent floods); and low probability of floods or other extreme events (ISPRA, 2021). The hazard measure ranges between 0 and 1 according to the area that lies in each of the three groups, and a weighted average was calculated and also normalised between 0 and 1 to get a comprehensive flood hazard variable for the municipality. In our estimation of the propensity score, the municipality risk variables (vulnerability, resilience, exposure and hazard) are considered to be time-invariant.[8]

To account for possible differences in the pre-trends of the outcome variables between treated municipalities and controls, we estimate a separate propensity score for each dependent variable, including as a covariate the six-month change in (log) outcome prior to treatment. Finally, as we also want to provide evidence about the heterogeneous effect for municipalities with different levels of resilience and vulnerability, we also interact these pre-trends with our dummies for resilience and vulnerability. To be as flexible as possible in the identification of good matches, we estimate each probit separately for each month when at least one event occurred.[9]

We match each treated municipality to the two nearest neighbours in terms of predicted propensity score and impose a *caliper* to limit the bias arising from bad matching.[10] Exact matching between treated and controls in terms of resilience and vulnerability is imposed.[11]

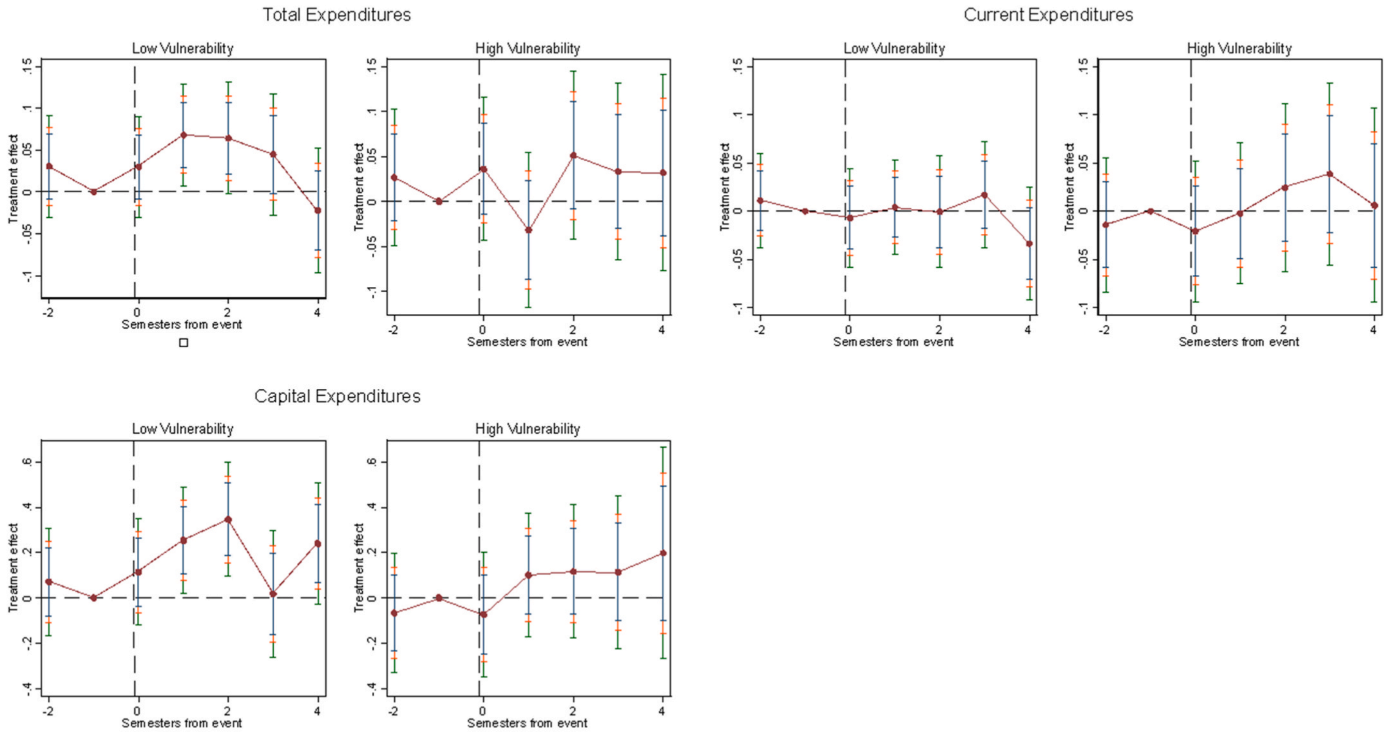
[7] Concerning households' taxable income, the database of the Ministry of Economy and Finance provides information on the sum of incomes declared by residents of the municipality that is subject to the general income tax for individuals (IRPEF). In our estimation of the propensity score, we included the lagged value of this income.

[8] In contrast, income and population are time-varying variables. However, given that we only have information on yearly change and the high persistence of these variables, we included them in our propensity score with a 1 year.

[9] February 2014, March 2014, September 2014, October 2014, November 2014, February 2015, March 2015, September 2015 and October 2015. The results based on a single propensity score for all the events are very similar to the ones reported in the article and are available upon request.

[10] We apply the usual rule of thumb to set the caliper to 1/4 of the standard deviation of the predicted propensity score.

[11] As an additional robustness check, we add one additional dimension to the exact matching; that is, the quartile of the outcome's six-month pre-trend. The results are reported in Appendix C.



Note: Three levels of statistical significance are reported: p-value < 0.1 (blue), p-value < 0.05 (orange), and p-value < 0.01 (green).

Fig. 7. Estimations by Vulnerability Level: Expenditures
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To test the validity of the matching based on the propensity score, we test whether treated and controls share the same average characteristics by means of a simple *t*-test. We contrast these mean comparisons with a mean comparison between treated municipalities and all (matched and unmatched) untreated municipalities to understand whether the matching improves homogeneity in the two groups of treated and controls. Our results are reported in Appendix B, Tables B.1.1 and B.1.2. They suggest that the matching substantially reduces the bias that could arise if municipalities with systematically different characteristics had systematically different trends in the outcome variables. All the observable characteristics show no statistical difference, on average, between treated and matched municipalities at conventional levels of statistical significance after matching on the propensity score. Instead, if we consider all the untreated municipalities as control groups, the differences were generally significantly different from zero (see Table B.1.1).

Fig. 2 maps treated and matched control municipalities. There are517[12] treated municipalities and, based on propensity score matching, 2117 matched control municipalities (for at least one outcome variable).

[12] Specifically, the whole sample of treated municipalities has 785 observations. Despite this, we only account for 517 because their pre- and post-trends can be fully observed in our reference period (2013–2016). In this way, we avoid the risk of including in the pool of non-treated municipalities those that were affected by flooding prior to 2013 or after 2016, for which we do not have information.

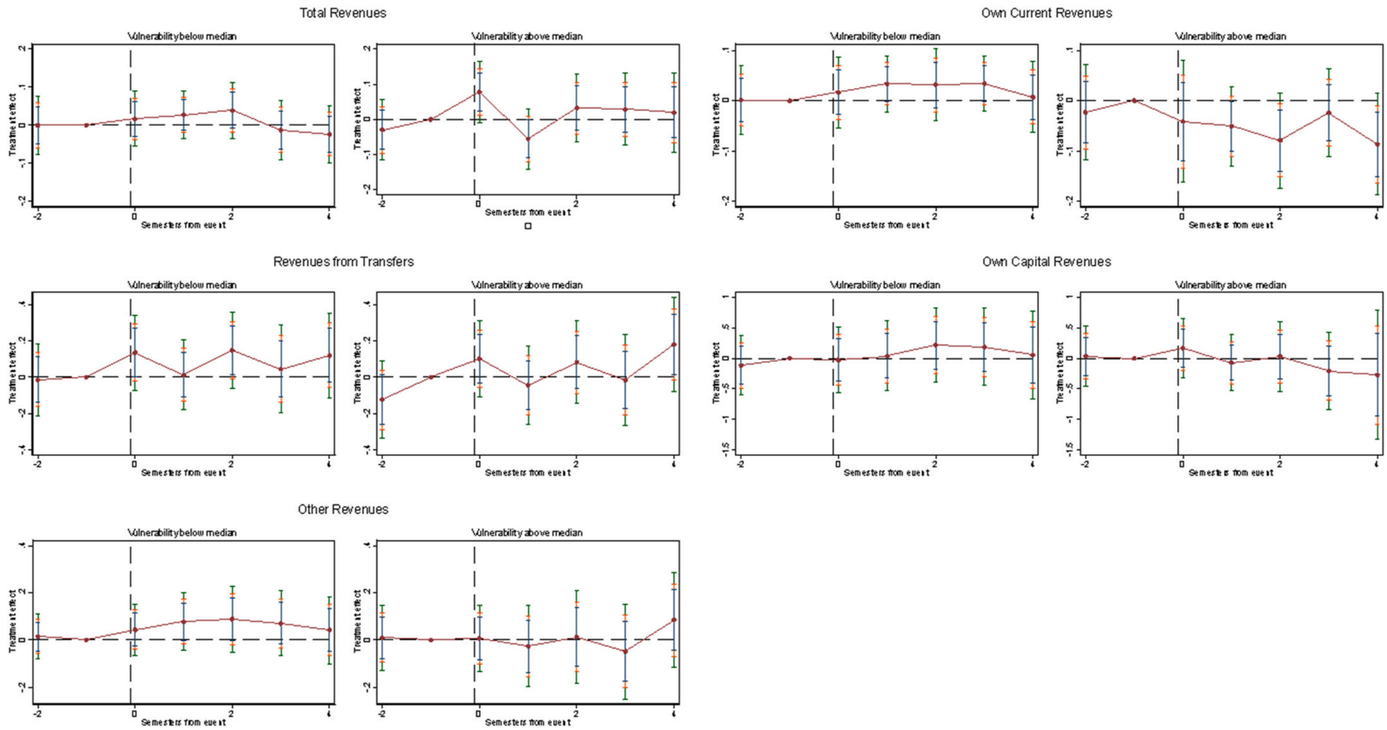
5. Results

5.1. Baseline results

The dynamics of our estimated average treatment effect of floods on municipalities' budgetary outcomes are reported in Fig. 3 (expenditures) and 4 (revenues). Generally speaking, no significant pre-trend exists, so any post-treatment deviation of the trends between treated municipalities and the counterfactual could be ascribed to the extreme event.

In all the figures, when "semesters from event" equals 0 ($t = 0$), we are referring to the "event semester." The treatment effect on total expenditures is positive until the third semester after a flood; it reverts to zero in the fourth semester. In terms of magnitude, the effect is sizeable: from +3.4% in the event semester to +6% in the third post-treatment semester. Regarding the precision of the estimates, the effects are statistically different from zero in the event semester (p-value <0.1) and the second (p-value <0.01) and third (p-value <0.1) semesters. These results indicate that local governments react to flooding quite soon by increasing expenditures, even though the full potential is reached one year after the flood. However, it seems that this effect tends to fade away quite rapidly.

To dig deeper into the drivers of this overall effect, we consider expenditures in fixed capital (i.e., investments) and current expenditures separately. Public investments represent a large part of expenditures aimed at boosting the recovery and reconstruction of infrastructure and buildings that were directly hit by the flood. The effect of a flood on capital expenditures (bottom-left panel of Fig. 3) only shows up in the second semester after the flood ($t = 1$) and further grows in the third semester ($t = 2$). This effect is statistically different from zero (p-value <0.1) and quite large in magnitude; it corresponds to an increase (compared to the counterfactual) of 19% in the second semester and



Notes: Three levels of statistical significance are reported: p-value < 0.1 (blue), p-value < 0.05 (orange), and p-value < 0.01 (green).

Fig. 8. Estimations by Vulnerability Level: Revenues
Notes: Three levels of statistical significance are reported: p-value <0.1 (blue), p-value <0.05 (orange), and p-value <0.01 (green). . (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

26% in the third semester. Considering current expenditures (e.g., personnel expenditures), we find no significant effect on treated municipalities in the aftermath of a flood; this might signal that climate disasters provoke immediate impacts on municipal capital and physical assets, which wear off when these assets are replaced.

When focusing on revenues (Fig. 4), we observe that the effect of floods on total revenues is characterised by a non-monotonic trend. An instantaneous (t = 0) significant increase in total revenues happens when the shock occurs, which corresponds to a +4.9% increase (significant at 5%). This effect is immediately reabsorbed in t = 1. In the third semester (t = 2), revenues are subject to a new increase (not statistically significant) and then start to steadily decline.

By adopting the same approach as with expenditures, we break down total revenue into its main components. Interestingly, no significant effects are found for current, capital and other revenues. However, when considering revenues from transfers, we estimate a positive and significant impact in the event semester and the third semester. This effect suggests that at least part of the additional expenditures borne by local governments was financed by national or other subnational governments. At the same time, it seems that local governments do not significantly change their revenues by suspending or postponing the collection of local taxes to support the different economic agents (citizens, workers, companies) affected by flooding. Furthermore, floods do not seem to have a substantial (positive or negative) influence on the local tax base. Therefore, the system seems to be based on central government transfers to meet the necessary additional allocations. This could encourage free riding if local institutions choose not to invest in prevention and mitigation, especially by considering that imposing new taxes on the territories affected would turn into a sort of fiscal punishment that is going to be added into the costs already generated by an event. To summarise, in Italy, flooded municipalities tend to respond by boosting the level of public investment (with a six-month delay), which is financed (at least partly) by increased transfers from other levels of government. This result suggests a good capacity to cope with extreme events and act with the aim of enhancing post-flood recovery. In contrast, no change is observed in terms of current expenditures and other revenues, which means that the events in question did not substantially erode the tax base and that local governments did not change local tax rates.

5.2. Heterogeneous effects: high-vs low-resilience municipalities

Since municipalities react differently to extreme climate events depending on their characteristics, we provide evidence about the effect's heterogeneity based on the level of resilience and vulnerability. Most studies of economic resilience and vulnerability support the notion that a system's ability to react to and cope with shocks varies according to its characteristics. However, to our knowledge, few studies have shown the actual mechanism through which a resilient system is better able to cope with unexpected shocks. In our work, we show how the ex-ante more resilient and less vulnerable municipalities are able to cope with unforeseen events through their capacity to better use internal budgetary resources, while less resilient and more vulnerable municipalities mostly depend on transfers. Overall, our work may be considered an explicit test of the capacity of resilient municipalities to cope with unpredicted shocks and the ensuing socioeconomic vulnerability (see Table 1).

We consider the median value of resilience and vulnerability as the threshold to identify high-vs low-resilience/vulnerability municipalities. As shown in Table 2, 35.20% of treated municipalities are highly resilient and less vulnerable to floods. Less resilient and more vulnerable damaged municipalities are similarly represented in the sample (38.88%). The residual 26% is distributed between less resilient/less vulnerable (14.12%) and highly resilient/highly vulnerable (11.80%)

treated municipalities.

First, we break down our sample by resilience; the results are reported in Fig. 5 (expenditures) and 6 (revenues). In general, less resilient municipalities hit by floods do not change their pattern of (total, current and capital) expenditures; the effects are not statistically different from zero, with the sole exception of the increase in total expenditures in the second semester after the event semester (p-value <0.05). In contrast, we find large and significant effects for resilient municipalities, especially for capital expenditures and total expenditures; we also estimate a positive and significant effect on current expenditures in the third post-treatment semester. In summary, municipalities with high resilience respond quite promptly to flooding by boosting spending in infrastructures and other capital expenditures to favour post-disaster recovery. Moreover, these municipalities also boost current expenditures in the long run. The response to floods of less resilient municipalities is much weaker. This is one of the first pieces of evidence that shows the mechanism through which more resilient municipalities are better able to face extreme events thanks to their higher capacity to handle greater flows of (internal) resources, without waiting for external aid. This highlights two important findings of this work: 1) more resilient subjects have a higher capacity to quickly spend money, thereby immediately starting the recovery process; 2) more resilient subjects are more aware that investments are important to facilitate post-disaster recovery.

The results for revenues, broken down by level of resilience and revenue type (Fig. 6), indicate that less resilient treated municipalities record a statistically significant (p-value <0.1) and substantial increase in total revenues in the semester of the flood with respect to the corresponding counterfactual, which is mostly driven by a substantial increase in transfers from higher or equal levels of government. This does not happen to more resilient municipalities, for which we find no immediate rise in total revenues and a smaller (and not significantly different from zero) increase in transfers compared to less resilient ones, while some evidence of a significant increase in transfers appears in the last observed semester.[13]

Our results suggest that other national or subnational governments (e.g., NUTS2 regions) immediately transfer funds to support less resilient municipalities and that these transfers are not effectively used by local authorities with poor resilience. At the same time, highly resilient municipalities promptly respond to a flood by boosting capital expenditures, even without any significant transfer of resources from other levels of government.

5.3. *Heterogeneous effects: high-vs low-vulnerability municipalities*

To corroborate our results on resilience, we replicate our analysis by looking at the vulnerability of municipalities. As mentioned before, resilience and vulnerability are strongly negatively correlated (correlation coefficient of −0.77). From our perspective, resilience and vulnerability share some common characteristics but are two separate concepts that capture socioeconomic differences among municipalities. This is reflected in the composition of the two indicators of resilience and vulnerability. Roughly speaking, we suggest that resilience is the capacity of a municipality to prevent damages from becoming embedded in the economic system through a slowing down of economic growth, while vulnerability is related to the capacity to suffer socioeconomic losses.

Fig. 7 shows the differential effects broken down by the level of vulnerability for expenditures. As expected, these results mirror those broken down by resilience (Figs. 5 and 6). We estimate a substantial increase in total expenditures, driven by capital expenditures, in the aftermath of a flood (compared to the counterfactual) for municipalities with a low level of vulnerability. No significant effect is found for current expenditures nor for high- or low-vulnerability municipalities.

Focusing on revenues (Fig. 8), by comparing less vulnerable treated municipalities with the corresponding counterfactual, we can see that the former experienced an increase in total revenues until the second semester after the event semester and then a decrease. We do find some peculiarities when considering vulnerability instead of resilience. In the aftermath of the flood, more vulnerable municipalities show an increase in revenues (not entirely explained by an increase in transfers, which is not statistically different from zero), while less vulnerable ones experience an increase in transfers. We also observe a negative and significant post-flood effect on own current revenues for more vulnerable municipalities; this might signal a higher impact of the flood in more vulnerable municipalities in terms of a reduced tax base (e.g., because of a reduction in the number of economic actors in the locale and/or prolonged tax cuts or exemptions).

6. Conclusions

Observing that a growing number of floods have affected Italy in recent decades and considering their impact on local economies, in this article we investigated the effect of flooding on the short-term budgetary choices of local (municipal) governments, focusing on 4185 municipalities in nine Italian regions over the 2013–2016 period. We used a dynamic difference-in-differences model with an a priori identification of proper counterfactuals through propensity score matching.

On average, Italian municipalities respond to flooding events by fostering public investments; this expenditure growth is partly financed by increased transfers from other levels of government. This result highlights the capability of municipalities to cope with floods and react by boosting post-flood recovery. Moreover, the floods in question do not affect the tax base, and the municipalities do not change local tax rates. A system that is fully funded through taxation represents a sort of "bet with nature" that incentivises bad government behaviour, as taxation is seen as cost-neutral with respect to spending in loss prevention. As a result, governments forego prevention and mitigation activities (Modica et al., 2019a). Still, other ways of funding or financing sources aimed at meeting additional allocations might depend on the peculiar characteristics of the affected individuals and territories.

We extended our analysis to heterogeneous effects based on the ex-ante resilience and vulnerability of the municipalities in question. The results show that more resilient and less vulnerable municipalities can cope with unforeseen events because they can invest available internal budgetary resources. These municipalities do not have to wait for external aid. Less resilient and more vulnerable municipalities highly depend on transfers from other national and subnational levels of government.

Our findings have interesting policy implications. They can support policymakers in planning general disaster management as well as the relationship between national and local levels of government in disaster and reconstruction management. For instance, Italy is currently discussing a draft law on the adoption of a Code of Reconstruction. We believe that our results could make a pivotal contribution to this debate for at least two reasons.

First, as municipalities respond to floods by increasing their capital investments without an adjustment of their revenues, substantial imbalances can be generated in their financial budgets. This finding points to the need to grant some degree of flexibility to incur deficits in the aftermath of a disaster. Second, the prompt response in terms of increased capital expenditures appears to be larger for more resilient and less vulnerable municipalities. Therefore, the ex-ante capacity to cope with extreme events and limit damages is a good predictor of a municipality's post-disaster recovery capability. In this respect, the implication is not straightforward. On one hand, the long-term strategy for local and regional-national governments should be to enhance the resilience of municipalities and reduce their vulnerability. On the other

[13] "Other revenues," which are mainly connected to revenues from services provided on behalf of third parties, appear to be positively affected by a flood in highly resilient municipalities.

hand, in the short term, there is room for direct intervention by the regional or national government in terms of direct capital spending in flooded, less resilient and more vulnerable areas. Relatedly, our findings highlight that the transfer of funds to local governments in less resilient and more vulnerable municipalities is not enough to boost local capital expenditures. This means that the failure to increase capital expenditures in these municipalities does not depend on tight financial or regulatory constraints but on the inability to operationalise additional spending in the short term.

This article can represent a starting point for future research. It would be very interesting to consider the political-economic mechanisms behind a municipality's budgetary dynamics by examining, for example, a mayor's characteristics and the electoral cycle. Furthermore, the econometric approach used here could be employed to estimate the effects of other extreme natural events, such as earthquakes, which also strongly affect the Italian peninsula. Finally, a similar approach could be applied to the private sector (i.e., firms) to investigate if it responds to extreme events in the same way as the public sector.

Credit author statement

Chiara Lodi: Conceptualization, Methodology, Data curation; Investigation; Formal analysis; Validation; Writing – original draft Preparation; Writing – review & editing, Giovanni Marin: Conceptualization, Methodology; Formal analysis; Validation; Supervision; Resources; Writing – original draft Preparation, Marco Modica: Conceptualization, Methodology; Formal analysis; Supervision; Writing – original draft Preparation

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2023.117352.

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