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## Going NUTS: The regional impact of extreme climate events over the medium term

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## Working Paper Series

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### Going NUTS: the regional impact of extreme climate events over the medium term

No 3002

## **Abstract**

The projected increase in extreme climate events in the coming decades is likely to exacerbate the existing productivity and demographic challenges facing Europe. We study the dynamic, medium-run macroeconomic effects of heatwaves, droughts and floods in 1160 EU regions through the lens of a local projections, difference in difference framework. Summer heatwaves and droughts lower medium-term output, but the impact from floods depends on regional income levels. High-income regions witness reconstruction activity, less wealthy regions do not. We find evidence of population decline in affected regions as well as adaptation spending post-event, which lowers regional productivity.

*JEL classifications:* D24, E24, J22, R11, Q54.

*Keywords:* Extreme climate, weather, potential output, labour market, productivity, local projections, difference in difference.

## Non-technical summary

Extremes of climate – such as floods, droughts and heatwaves – can have substantial human, social and economic impacts. These events are predicted to become more commonplace and more devastating with climate change. Previous research has highlighted that these events can affect economic activity at the national level, particularly in the short term. In general, the impact on European economies has to date been smaller than that observed in emerging and developing economies.

However, those national-level impacts may underestimate the full impact of such events over the long run, particularly in the context of a changing climate. First, while the short-run costs are generally confined to the immediate damage and disruption caused by the events, changes to investment, labour supply, and productivity could potentially prolong the economic effects into the medium term. Second, extreme climate events are often relatively local. Local and regional European economies have access to strong risk-sharing mechanisms, which can both help alleviate local economic damages, and produce positive spillovers to neighbouring regions. Finally, the effects of extreme climate events can depend on initial climate conditions. As climate change results in changes to baseline temperatures and precipitation patterns, the economic consequences may worsen.

Studying the medium-run impact of extreme climate at the lowest possible level is therefore crucial at this juncture. We do so in the context of EU regions at Nomenclature of Territorial Units for Statistics (NUTS) level 3, for which we have both data on aggregate economic activity from regional accounts, as well as data on extreme climate events derived from climate and weather data using the high-resolution hourly weather ERA5 “reanalysis” dataset. Looking at the more localised impact provides a number of insights.

First, we find that a number of economic, geophysical and seasonal factors matter for the total impact. Summer heatwaves typically reduce economic activity, whereas heatwaves in winter can boost activity. The effects of summer heatwaves also differ between those regions that are generally hotter on average and those that are generally colder. Finally, we find average income and the sectoral composition to determine the degree to which heatwaves affect regional economies, too.

Second, we show that these extreme events can have a lasting impact on regional output beyond the initial disruption caused by the event. Indeed, we find evidence that the economic



effects can increase over time as the initial disruption and destruction can create uncertainty in demand and productivity, resulting in lower investment and capital over time. Output is 1.4 percentage points lower four years after a region is affected by a summer heatwave and 2.4 percentage points lower four years following a drought. Residents of affected areas may also emigrate, reducing the availability of workers.

Third, we investigate what drives that longer-run aggregate impact by considering the evolution of the three main factors of production: capital (which includes factories, machinery, and infrastructure); labour (the total number of hours worked in the region over the course of the year); and total factor productivity (TFP, which includes technology as well as how efficiently the other factors work together). We find that each type of event triggers distinct dynamics for the various productive inputs, the underlying causes of which can have far-reaching policy implications.

For summer heatwaves, the initial fall in output is largely explained by lower employment and lower hours worked. Over time, affected regions witness an increase in investment and capital, but lower TFP and unchanged output. This suggests that there is substantial investment in adaptation (such as air conditioning or improving insulation), which may help mitigate the impact of future heatwaves, but does not increase output by as much as investing in productive capital would. Droughts lead to lower investment, lower employment and lower TFP, thus lowering output over the medium term. For floods the picture is less clear, as we find no overall impact on output over the medium term. In high-income regions, the event is followed by more investment and GDP suggesting a reconstruction boom. There is evidence of higher TFP in these regions, too, suggesting that it may be possible to “build back better.” But this higher investment does not occur in lower-income regions, suggesting that financial constraints may dampen the recovery and worsen long-run outcomes.

# 1 Introduction

The economic stability of the Great Moderation at the dawn of the 21st Century has given way to economic turbulence. The past two decades have witnessed the Global Financial Crisis, the Great Recession, the COVID pandemic and more recently Russia’s invasion of Ukraine. These shocks have all been temporary, albeit persistent. Yet the coming decades risk continued disturbances from worsening structural trends and ever-growing shocks. In the words of Christine Lagarde, “*As central bankers, we are now facing a fundamentally different environment: one characterised by more instability, more volatility and more uncertainty about the very structure of the economy*” (Lagarde, 2024). Draghi (2024) highlights the economic challenges arising from weak productivity growth and the declining population.

Against this background of heightened economic uncertainty, we investigate the macroeconomic impact of extreme climate events. That these events will become more frequent and more intense over the course of the coming decades looks to be an unfortunate certainty (IPCC, 2021). Our findings demonstrate that worsening extreme climate events are likely to exacerbate the economic challenges of low productivity growth and demographic pressures. Affected regions appear to invest in adaptation in the aftermath of events, which lowers overall productivity. On top of that, they also witness population declines.

More precisely, we analyse the causal effects of extreme climate events – including heat-waves, floods and droughts – on medium-run output by estimating the responses of output and its individual components over a five-year period. Potential output, which can be defined as the medium-run trend level of output that an economy can sustain without generating inflation, has three main components: the capital stock (including machinery, buildings and infrastructure), labour supply, and total factor productivity (TFP). The macroeconomic effects of extreme weather events can, therefore, prove durable and become important for inflation developments and monetary policy over the medium term if they persistently affect one or several of these components.

Our proposed approach introduces three novelties with respect to the literature. First, we use a growth-accounting exercise to tease out the economic forces behind these medium-run effects. We use our data on output, capital, and hours worked to compute aggregate regional total factor productivity (TFP). Analysing the underlying productivity, investment, and labour dynamics over a five-year horizon, we can interpret the different economic channels through which

different physical hazards affect the aggregate economy of regions. Heatwaves, for example, do not necessarily create large economic losses in the short run; they might affect productivity negatively, thus disincentivising investment and output in the long run. Droughts, on the other hand, mainly seem to operate through the labour market in the medium-run by lowering employment and hours worked, while also slightly reducing productivity and investment. This might be a sign that these phenomena mainly affect output through their impact on worker efficiency rather than directly affecting capital.

Several authors have identified a (usually negative) impact of extreme events and disasters on near-term economic activity (e.g. [Noy, 2009](#); [Dell et al., 2012](#); [Fomby et al., 2013](#); [Felbermayr and Gröschl, 2014](#)). The near-term impact arises primarily from the destruction and disruption of the event itself, reflected in actual output and the output gap. This disruption may dissipate over time as reconstruction takes place, making the impact on potential output small. The literature on the medium-term effects of disasters is sparser and has generally focused on GDP alone. Nonetheless, it has identified some events that had more persistent consequences for activity. For example, [Vigdor \(2008\)](#) and [Hornbeck and Naidu \(2014\)](#) find evidence of outward migration from regions heavily affected by Hurricane Katrina, and the 1927 Mississippi floods, respectively. [Bier \(2017\)](#) provides a broader review of the literature on post-disaster migration. [Noy and Strobl \(2023\)](#) find that hurricane strikes tend to result in a lower rate of innovation over the medium term. By contrast, [Leiter et al. \(2009\)](#) find some evidence of positive impacts on assets and employment of firms in regions affected by flooding, particularly those with a greater share of intangible assets, but lower overall productivity. The type of investment in the aftermath of extreme events may also affect medium-term output and productivity. Investment in adaptation capital in affected regions may reduce the incidence of future events, but is likely less productive than existing capital and may therefore lower overall TFP (see, for example, [Parker, 2023](#); [Bijnens et al., 2024](#)).

The second innovation we introduce is undertaking our analysis for EU regions at the Nomenclature of Territorial Units for Statistics (NUTS) level 3. Regional impacts have, to date, received much less attention than the national level. Investigating local economies can help provide greater evidence of the factors that can mitigate or exacerbate the economic impact of extreme events, including geographical and structural economic characteristics, while leaving out the confounding effects of inter-regional transfers, migration, and firm relocation that cannot be controlled for when using national-level data. It also provides a much larger sample of controls

for the analysis. [Kotz et al. \(2021\)](#) find that daily fluctuations of temperatures can affect output in a global panel of regions, and [Kotz et al. \(2022\)](#) find an effect of variations in precipitation on growth. Compared to them, our more homogenous sample of European regions can help with identification by reducing the possible biases introduced by not capturing the large geographical, economic, and institutional differences across their regions. [Roth Tran and Wilson \(2020\)](#) find that disasters can have a positive impact on local output in the United States, in contrast to much of the literature carried out at the national level. This result may partly be a consequence of their sample of extreme events, which only includes those events where federal aid was provided. As shown by [Noy and Nualsri \(2011\)](#), higher fiscal spending in the aftermath of disasters ameliorates the outcome. In contrast to them, we include extreme weather events irrespectively of the national transfers our regions might have received.

Finally, using a local projections approach to the difference in difference framework, as proposed by [Dube et al. \(2023\)](#), alongside clean treatments and controls, lets us take full advantage of our regional data to identify the causal effects of extreme weather events on the macroeconomy. Our approach has two main advantages. First, analysing extreme weather events in isolation helps us control for probable "complementarities" across event types, as well as either cumulative effects of consecutive events, or the damping effects of adaptation. Second, the flexibility of the local projections framework lets us explore the inherent dynamics of the macroeconomy while capturing heterogeneous, non-linear effects of acute physical hazards across regions depending on their climate and level of economic activity, as well as the patterns and severity of the initial climate event.

Our approach not only shows that the impact of extreme weather events is heterogeneous across event types and regional characteristics, it can also intensify over time. Output is 1.4 percentage points lower four years after a region is affected by a summer heatwave, and 2.4 percentage points lower four years after a drought. A simplistic view of an extreme event being characterised as an initial destructive and disruptive shock followed by rehabilitation and reconstruction seems poorly supported by this evidence. A better characterisation would appear to be that uncertainty, income losses, disruption and emigration can depress demand, and the lower activity and employment can persist, and endogenously lower potential output. This latter characterisation is in line with the finding of [Faccia et al. \(2021\)](#) that heatwaves can lower inflation over the medium term and of [Natoli \(2023\)](#) and [Cantelmo et al. \(2024\)](#) that disasters can lower output through reducing demand. It also accords with the recent findings of [Bilal and](#)

[Känzig \(2024\)](#) who find that the GDP impact of global temperature shocks is persistent and continues to grow even once the initial temperature shock has already faded.

The rest of the paper is organised as follows. Section [2](#) describes our data and definitions. Section [3](#) presents the method we use to estimate the medium-term impacts of extreme weather events on the components of regional potential output. Section [4](#) analyses the macroeconomic effects of heatwaves, floods, and droughts in depth. Finally, Section [5](#) concludes.

## 2 Data and variables

This section sets out the sources for the extreme events, regional economic and structural data that are used in the following analysis.

### 2.1 Extreme event variables

The economic literature on extreme events has historically used two types of sources to identify the existence of extreme events. Early studies generally relied on ex-post measurement of disasters, most notably the EMDAT database. EMDAT defines a disaster as “*A situation or event which overwhelms local capacity, necessitating a request to the national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction, and human suffering.*” [Roth Tran and Wilson \(2020\)](#) similarly select extreme events based on those where the economic impact have been large enough to elicit federal funding in the United States.

As noted by [Felbermayr and Gröschl \(2014\)](#) and others, using ex-post measurement of disasters has several drawbacks. First, inclusion in the database may be correlated with GDP per capita since the value of damage is likely to be higher in richer countries. Second, the impact is itself endogenous to economic conditions. For a given underlying extreme weather or climate event, the ultimate impact depends on what economic activity is exposed to the event and how resilient that activity is to the event. Adaptation, such as flood protection, irrigation or air conditioning, can reduce the impact and, therefore, reduce the likelihood that an event turns into a disaster.

For these reasons, we favour the use of climate and weather data, in line with the approach of [Kotz et al. \(2021\)](#) and [Kotz et al. \(2022\)](#). Using extreme events based on historical averages enables us to study the geographical and economic factors that can result in differing regional

impacts of these extreme events. Moreover, these data enable an analysis of the effects on a consistent basis and do not suffer from potential omissions as EMDAT and similar datasets do.

Data on temperature and precipitation for regional level taken from the ERA5 “reanalysis” dataset. The high-resolution hourly weather dataset has been accessed from the Copernicus Climate Data Store. The initial data are at grid level and aggregated to NUTS regional levels, weighting by population. We calculate the quarterly aggregates of the accessed data to match the data with macroeconomic data. The dataset includes a wide range of information on meteorological variables including temperature, precipitations, snow, wind etc. The final sample includes 1160 NUTS-3 regions of 27 European Union countries from 1995-2022.

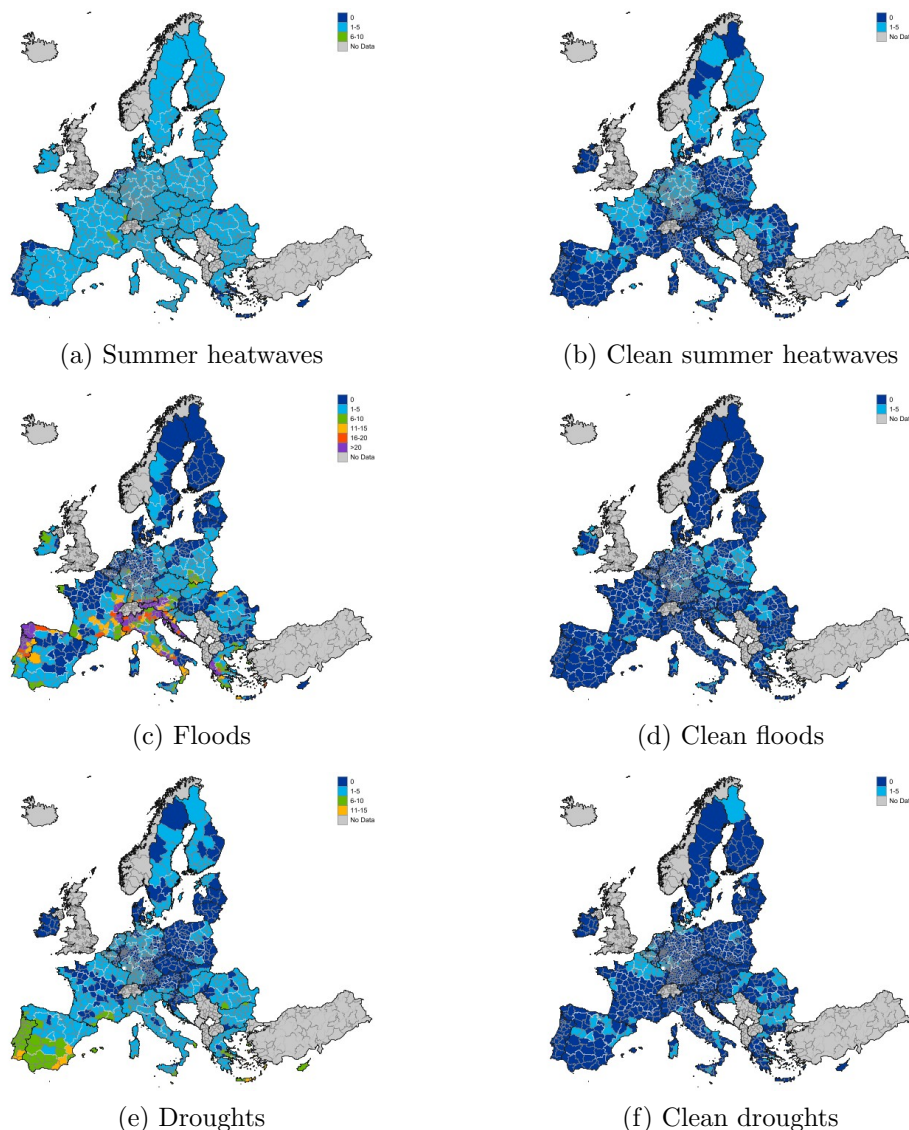
We calculate our extreme event variables, which we summarise in Figure 1, as follows:

**Extreme temperatures:** We aggregate the hourly weather observations to quarterly averages each season. Based on the meteorological calendar, we define winter (December-February), spring (March-May), summer (June-August) and autumn (September-November). We proceed in two steps to capture the effects of extreme temperatures on economic output. First, we define a “temperature anomaly” as the deviation of (annual/seasonal) observed temperature from the historical 1991-2020 mean temperature for the region, measured in degrees Celsius. The temperature anomaly includes positive and negative deviations from the long historical mean. The advantage of using anomalies is that they provide an estimate of the temperature “surprise” faced by the region. A summer daily maximum temperature of 30°C would be seen as extreme in some regions, but not in others. We also investigate whether differences in baseline temperatures matter.

In a second step, we define an “extreme temperature event” as a temperature anomaly that surpasses a critical threshold. Below this threshold, temperatures are assumed to be sufficiently close to historical averages that there is negligible economic impact. Concretely, our extreme temperature event variable is a binary variable which takes the value 1 if a seasonal temperature anomaly exceeds the threshold of  $\pm 1.5^{\circ}\text{C}$ , and 0 otherwise. This allows us to define hot seasons (summer, spring, autumn and winter), when a temperature anomaly reaches at least  $1.5^{\circ}\text{C}$ . We define seasons as being cold when the anomaly goes below  $-1.5^{\circ}\text{C}$ . But we only have sufficient observations for cold winters, and do not find significant impacts. As a result, we focus on heatwaves in what follows.

**Precipitation extremes:** We similarly define floods and droughts using anomalies relative to historical precipitation patterns, although the two types of events typically develop differently

Figure (1) Extreme event occurrence across the entire sample



Note: Figure 1 shows the regional distribution of measured extreme weather events for 1995-2022, as well as the distribution of "clean events" as defined below.

over time. Floods are generally the result of substantial precipitation within a short period, whereas droughts generally develop more slowly, rather than as a result of a week or two without rain.

**Droughts** We define a drought, therefore, as an indicator variable for each year and region that takes the value 1 if at least three consecutive months have precipitation below 50 percent of the long-run (1991-2020) monthly mean, following (Felbermayr and Gröschl, 2014).

**Floods:** We predict flood events by calculating standardised precipitation index (SPI) using



methodology suggested by (Copernicus European Drought Observatory (EDO), 2020). The index measures precipitation anomalies at a given location based on observed total precipitation, and this historical data is fitted to a probability (gamma) distribution. To calculate the index, the fitted probability distribution is normalised such that SPI value for a region and period is zero. The value of SPI between -1 to +1 shows normal precipitation conditions, whereas, values above +1 show excess rainfall and above +2 imply extreme rainfall. Therefore, we define floods as events when SPI takes value above 2 inclusive.

## 2.2 Economic data and other regional characteristics

The NUTS hierarchical system classifies EU regions into three main levels for statistical purposes. These include NUTS-1, which encompass the major socioeconomic regions, NUTS-2, which usually describe regions with autonomous policy-making capabilities, and finally NUTS-3 regions, which are more local. We use regional-level data at the NUTS-3 level on the gross regional domestic product, gross regional product per capita, labour market variables, productivity and investments from Eurostat, AMECO and ARDECO databases. Most of these variables are available only at annual frequency, which is sufficient for the focus here on longer-run impacts as the immediate impact in the quarter of the event is not relevant.

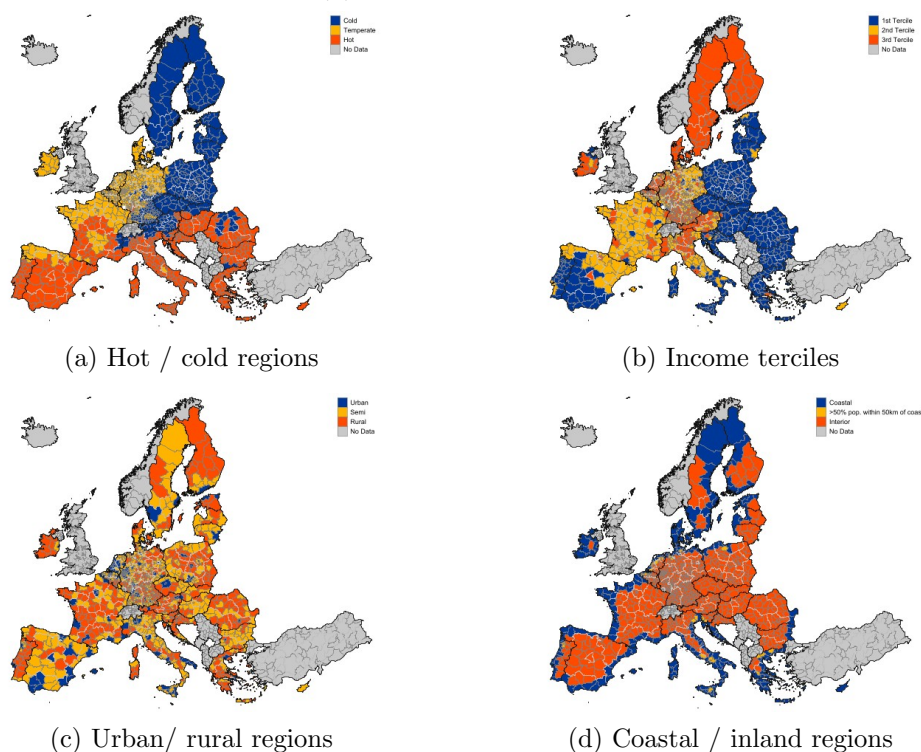
We further split our regions by differing types, summarised in Figure 2, to understand geophysical and economic factors that may mitigate or magnify the impact of extreme events.

**Hot/cold regions:** To control for baseline climate conditions in the regions, we define hot and cold regions. We divide the data into terciles based on average quarterly temperature during summers for 1991-2020, coinciding with the baseline average for calculating anomalies. Those in the third tercile have the highest temperatures and are termed hot regions. To define cold regions, we again split the sample based on average quarterly temperature during winter for 1991-2020, and the regions in the first tercile have the lowest average temperatures and are labelled cold regions. In what follows, we call regions in the middle tercile temperate regions, while recognising that the use of temperate may not necessarily align with climatological definitions.

**Income terciles:** The income level of a region can also affect its resilience towards a climate shock. Therefore, we divide our sample into three terciles based on GDP per capita (constant 2015 prices). The first tercile represents the lowest-income regions, the second tercile regions represent middle-income regions and the third tercile represents high-income regions.

**Urban / rural regions:** Using urban-rural typology for NUTS-3 regions, we divide the

Figure (2) Regional characteristics



Note: Figure 2 shows the regional distribution of annual average temperatures and other regional characteristics of interest for the year 2022.

sample into three groups: predominantly urban regions, intermediate regions and predominantly rural regions. The predominantly urban regions are those NUTS-3 level regions where more than 80 percent of the population live in urban clusters. In the intermediate group, between 50 and 80 percent live in urban clusters, and in predominantly rural group at least 50 percent of the population live in rural grid cells (Eurostat, 2021).

**Coastal / inland regions:** To explore if the effects of disasters differ across coastal versus inland regions, we divide the regions into three categories based on coastal typology NUTS-3 regions. The first group (295 regions) includes the regions which are on the coast, the second group (44 regions) include regions where more than 50 percent of the population is living within 50 km of the coastline, and the third group (821 regions) includes inland regions.

## 2.3 Sample

Table 2.1 provides a comprehensive summary of the key variables, detailing their mean values, standard deviations, minimum and maximum values, and total number of observations. The

dataset spans the period from 1995 to 2022, encompassing a variety of regional events and economic indicators across 1,160 regions, yielding a total of 32,471 observations. The variables, including real GDP, GFCF, and capital stock, are in million 2015 euro. Total hours worked are in thousand hours, average hours worked represent number of hours and total employment is given as thousand persons.

Table (2.1) Descriptive statistics

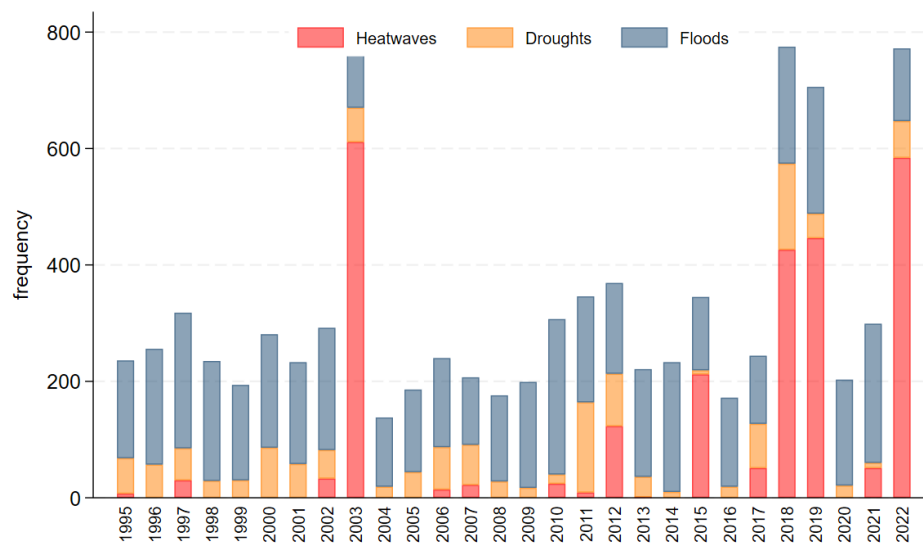
	Mean	SD	Min	Max	N
Regional gross domestic product (GDP)	9,777	17,144	66	239,191	32471
Gross fixed capital formation (GFCF)	2,059	3,659	9	62,690	32471
Capital stock	28714.86	47965.51	179.70	697561.13	32471
Labor share	62.17	3.62	47.96	71.32	32471
Total hours worked	279470.00	372858.31	2341.90	5892601.50	32471
Average hours worked	1648.27	235.42	1248.00	5371.00	32471
Total employment	167.81	222.47	1.30	3619.10	32471

Notes: Table 2.1 reports the summary statistics including mean, standard deviation, minimum, maximum and total observations. The variables, including real GDP, GFCF, and capital stock, are in million Euro2015. Total hours worked are in thousand hours, average hours worked are in hours and total employment is in thousand persons.

Figure 3 shows the frequency distribution of extreme events between 1995-2022. Our sample contains a considerably higher number of total extreme weather events, including floods, droughts and heatwaves, than the final number of clean events we use for our dynamic estimates. Floods are the most frequently observed type of event. However, we observe an increasing number of heat waves in the sample. The number of droughts, on the other hand, has decreased over time.

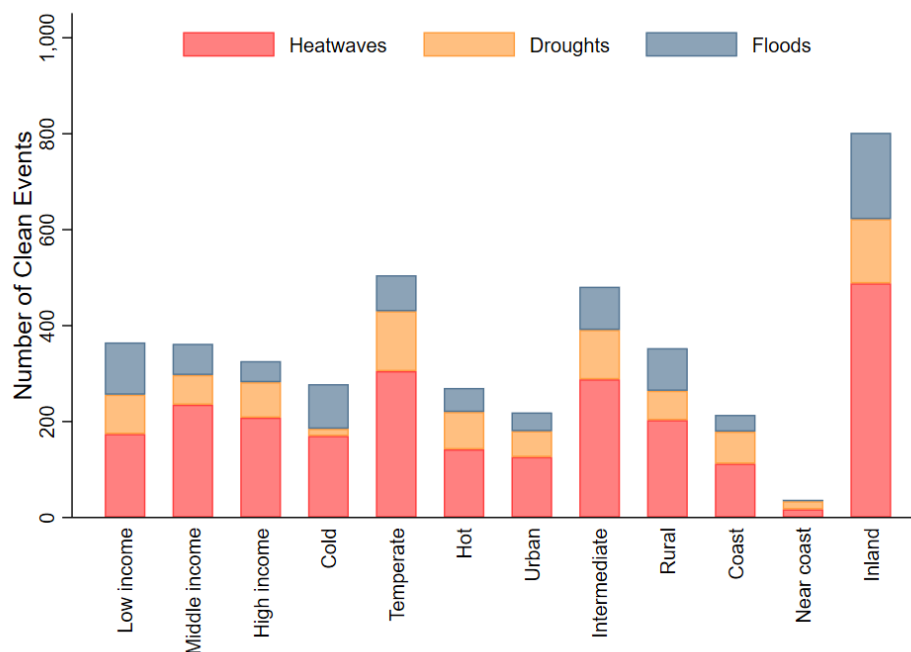
Figure 4 shows the clean extreme weather events across different types of regions. For each region type, we show the clean extreme events in our sample, and the clean events are defined in our framework as clean treatment and control units. The total events of extreme heatwaves, droughts and floods are 3,207, 1,803 and 4,885 respectively. The clean control treated events include 617 extreme heatwaves, 218 droughts and 218 floods during the sample period. As we are interested in exploring the differential impacts of disasters across various types of regions, our data provides enough observations to run heterogeneity analysis using the LP-DiD framework. The figure shows that the frequency of events varies significantly across region types; for instance, total events of heatwaves, droughts and floods are higher in inland regions than in coastal regions. Heatwaves are more frequent in inland regions relative to coastal areas. The total events in the middle-income group here represent the middle tercile of the income distribution.

Figure (3) Frequency distribution of total extreme weather events, 1995-2022



Note: Figure 3 shows the number of total extreme events in our sample for time period 1995-2022. The X-axis shows the years, and the y-axis shows the frequency of extreme events, including droughts, floods and heatwaves.

Figure (4) Clean extreme events by region type, 1995-2022



Note: Figure 4 shows the number of clean extreme events in our sample by region type. The X-axis shows the frequency of extreme events, including droughts, floods and heatwaves. Each bar represents the events by region type. For each region type, two bars show the clean extreme events in that region type and the cleaned treatments used in the regression analysis for that region type.

### 3 Methods

We divide our analysis of the macroeconomic effects of each one of the extreme weather events in our data into two broad parts. First, we estimate the immediate impact of severe and abrupt changes in weather conditions on yearly regional output, using a panel approach similar to that used in the literature to estimate impacts at the national level. We then turn to the medium-run developments on output, capital, labour, and total factor productivity by means of a growth accounting exercise.

#### 3.1 Short-run effects on output

The disruption caused by these extreme events and the initial reconstruction can severely affect output in the near term. We analyse the same-year impact of weather anomalies on regional GDP using a panel regression model with region- and time-fixed effects. This is a standard approach in the literature that studies impacts at the national level. We add four lags of the dependent variable in our specification to control for autocorrelation in output. Our baseline regression for the short-run effects of extreme weather events thus takes the following form:

$$y_{i,t} = \beta T_{i,t} + \sum_{j=1}^4 \gamma_j y_{i,t-j} + \alpha_i + \alpha_t + \epsilon_{i,t} \quad (1)$$

where  $y_{i,t}$  is the annual output in region  $i$  and period  $t$ , measured in natural log.  $T_{i,t}$  is a continuous variable that captures the corresponding weather anomaly, as described in Section 2. The summation  $\sum_{j=1}^4 \gamma_j y_{i,t-j}$  represents a sum over four lagged values of  $y$ , from  $j = 1$  to  $j = 4$ , meaning that the model incorporates the values of  $y$  from previous time periods and  $j$  is the lag index. Finally,  $\alpha_i$  and  $\alpha_t$  capture the regional- and time-fixed effects.

We also consider how regional baseline temperatures and seasons affect the impact of heat-waves. Following Colacito et al. (2019), we propose the following specification:

$$y_{i,t} = \sum_{s \in S} \beta_s D_{i,s,t} + \sum_{j=1}^4 \gamma_j y_{i,t-j} + \alpha_i + \alpha_t + \epsilon_{i,t} \quad (2)$$

$D_{i,s,t}$  is a dummy variable for each region  $i$ , characteristic  $s$ , and period  $t$ , which takes value 1 if a weather anomaly occurs in a year and region with a specific characteristic.

### 3.2 Growth accounting

We perform a growth accounting exercise to measure the medium-term impact of extreme events on output and understand better its drivers. The disruption caused by these extreme events and the initial reconstruction can affect actual output in the near term. However, the initial impact on production fades over the medium term. The dynamics of output in the following periods more likely reflects permanent changes to economic potential. The growth accounting exercise permits the study of how these events affect the main components of potential output: capital, labour and TFP. Understanding the evolution of each component helps interpret the channels through which these events affect a region's economy.

As a first step, we determine the impact of the weather anomalies on the individual components of the production function for each region. We assume a constant returns to scale Cobb Douglas production function at the regional level. We use the average labour share of income at the national level over our sample period, taken from AMECO, which we assume to be equal across regions within a given country. Finally, we back out TFP at the regional level given our data and assumptions.

To assess the impact of physical hazards on medium-run growth, we use the local projections difference in difference approach (LP-DiD) of [Dube et al. \(2023\)](#). Our LP-DiD specification is as follows:

$$y_{i,t+h} - y_{i,t-1} = \beta_h^{LPDiD} D_{it} + \sum_{j=1}^P \gamma_j^h y_{i,t-j} + \zeta_i + \delta_t^h + \epsilon_{it}^h \quad (3)$$

where  $y_{i,t+h}$  represents the corresponding dependent variable forward horizon in  $h = 0, 1, 2, 3, 4$  after the shock happens at zero horizon,  $\zeta_i$  controls for the characteristics of regions like its coastal/inland location,  $\delta$  controls for time effects and  $y_{i,t-j}$  are the lags of the dependent variables.

We study the impact over a five-year horizon, including the year of impact and the four subsequent years. To establish clean treatment and clean control groups for the estimation, we assume these events are non-absorbing and that the impact stabilises four years after the event. We also include two years prior to the event to account for pre-trends. We take into consideration all three types of events when establishing the treatment groups, such that the treatment group includes only those regions that have one event of the noted type over the full horizon and none of the other types. That enables us to distinguish the effects of the different event types, and in particular those of heatwaves from droughts, which may occur concurrently. The clean controls

are those regions that have no events over the full horizon, and the composition of each group is fixed for the years of analysis.

The selection of clean treatment and clean control groups is relatively strict. As shown in Figure 4, a substantial share of identified events are not included in our analysis. That exclusion comes with advantages – our analysis, therefore, excludes cases where there are repeated or concurrent extreme events which may pollute the estimates. It also excludes cases where droughts continue for several years. It is worth noting that to the extent that repeated events worsen the recovery for previous events, or compound events (such as droughts and heatwaves occurring at the same time) exacerbate outcomes, the results presented here are likely to be an underestimate of the economic impacts of extreme events.

## 4 Results: the macroeconomic effects of extreme weather events

In this section, we present the results of our analysis, starting with the short-run impacts of these extreme events, before setting out the medium-run impacts of, in turn, heatwaves, droughts and floods on output and its main components.

### 4.1 Short-run impact on output

Beginning with the short-term impacts, Table 4.1 shows the short-term effects of extreme weather conditions on regional output at NUTS-3 level, estimated through the two panel regressions discussed. The first column shows the impact of temperature anomalies on regional output. A 1°C increase in the anomaly reduces regional output by 0.26 percent. Neither droughts nor floods have an immediate effect on regional output in our sample (columns (3) and (4) in table 4.1).

Results show that annual deviations in temperature from historical means negatively affect output. Since the effects of deviations from a certain threshold vary across seasons, we interact our binary variable of extreme temperature with seasonal dummies, in line with Colacito et al. (2019). We define hot seasonal dummies which take the value 1 if the quarterly temperature deviation based on meteorological calendar is greater or equal to 1.5 °Celsius during that season. We then regress these seasonal dummies on regional output as defined in equation 2. We finally have four dummies including hot winter, hot spring, hot summer and hot autumn. The second column in Table 4.1 shows the impact of hot seasons on output. We observe a significant negative



Table (4.1) Short-term effects of extreme weather events on economic output

	(1) Annual Anomaly	(2) Seasonal Heatwaves	(3) Droughts	(4) Floods
Temperature Anomaly	−0.263*** (0.073)			
Summer heatwave		−0.509*** (0.085)		
Winter heatwave		0.462*** (0.092)		
Autumn heatwave		0.128 (0.102)		
Spring heatwave		0.006 (0.110)		
Drought			0.154 (0.110)	
Flood				0.0012 (0.102)
Constant	68.280*** (4.315)	68.385*** (4.290)	69.411*** (4.269)	69.340*** (4.660)
Observations	27484	27484	27820	27820
Time Effects	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>
Fixed effects	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>

Standard errors in parentheses

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ 

Notes: The first column of Table 4.1 reports the estimated coefficients on average annual temperature deviations (known as temperature anomalies and estimated as the annual mean of differences of monthly temperature from historical mean 1991-2020). These estimates are obtained from the regression of the annual regional GDP on its four lags and temperature anomalies using data from 1995-2022. The second column reports the estimated coefficient for the impact of heatwaves across seasons, which are dummy variables, and takes value one when seasonal anomalies are above the 1.5 degree Celsius threshold during that season. Seasonal anomalies are based on average seasonal deviations in temperature from the historical mean. The estimates show that both temperature anomalies (positive and negative deviations) significantly lowers the economic output of NUTS-3 regions). These estimates show that there is a differential impact across seasons on regional economic output. The third and fourth columns show the effects of floods and droughts on regional output. Both floods and droughts do not have an immediate significant effect on output. The regression framework controls for time and region-fixed effects, and standard errors are clustered at the regional level.

impact of hot summers and a positive effect of hot winters on regional output. However, there is no significant effect of heatwaves during autumn and spring.

After capturing the contemporaneous impact of heatwaves, we investigate the effects of extreme seasonal temperatures on economic output across hot and cold regions. To capture these non-linearities, we run a subgroup analysis for hot and cold regions, running regressions for each subgroup separately using Equation 2. We observe that the relationship between extreme temperature shocks and output varies depending upon the baseline climate of each region. Table

4.2 reports the estimated coefficients of hot seasonal dummies, which show the effects of positive temperature shocks (heatwaves) above 1.5°C, on regional output across hot, temperate and cold regions.

For the given sample, the estimates show that hot summers negatively affect the regional output of all three subgroups, although it is insignificant for hot regions. That insignificant impact may reflect the greater extent of adaptation in these regions, such as air conditioning. Cooler regions may be less prepared to cope with exposure to high temperatures. Heatwaves during spring positively affect the regional output of hot regions, while cold regions are negatively affected by spring heatwaves. Cold regions, however, are positively affected by hot autumns.

Table (4.2) Effects of seasonal heatwaves on economic output by region climate type

	(1) Cold regions	(2) Temperate regions	(3) Hot regions
Summer heatwaves	−0.3469* (0.1673)	−0.3810** (0.1426)	−0.2558 (0.1502)
Winter heatwaves	−0.1487 (0.1496)	−0.0277 (0.1949)	0.2959 (0.1778)
Autumn heatwaves	0.6606*** (0.1486)	−0.2661 (0.1973)	0.0390 (0.1998)
Spring heatwaves	−0.4574* (0.1958)	0.1070 (0.1984)	0.6098** (0.2132)
Constant	61.0161*** (5.9688)	121.9911*** (18.8717)	106.0496*** (11.6160)
Observations	7776	10512	9196
Time Effects	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>
Fixed effects	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>

Note: Table 4.2 reports the effects of heatwaves across different seasons(winter, spring, summer and autumn) on regional GDP (constant prices 2015) across cold, temperate and hot regions using data from 1995-2022. The variables "Summer heatwaves"/"Winter heatwaves"/"Autumn heatwaves"/"Spring heatwaves" take the value 1 when the observed temperature exceeds 1.5 °Celsius threshold relative to long historical mean in each meteorological quarter (represents a heat spell). Column(1-3) shows the regression of positive anomalies (rise in temperature) during each season. For each regression, controlling for hot or cold regions allows us to control for the baseline climate conditions of the regions. Hot regions belong to the third tercile of the distribution of average summer temperatures over the period 1991-2020. Cold regions belong to the first tercile.

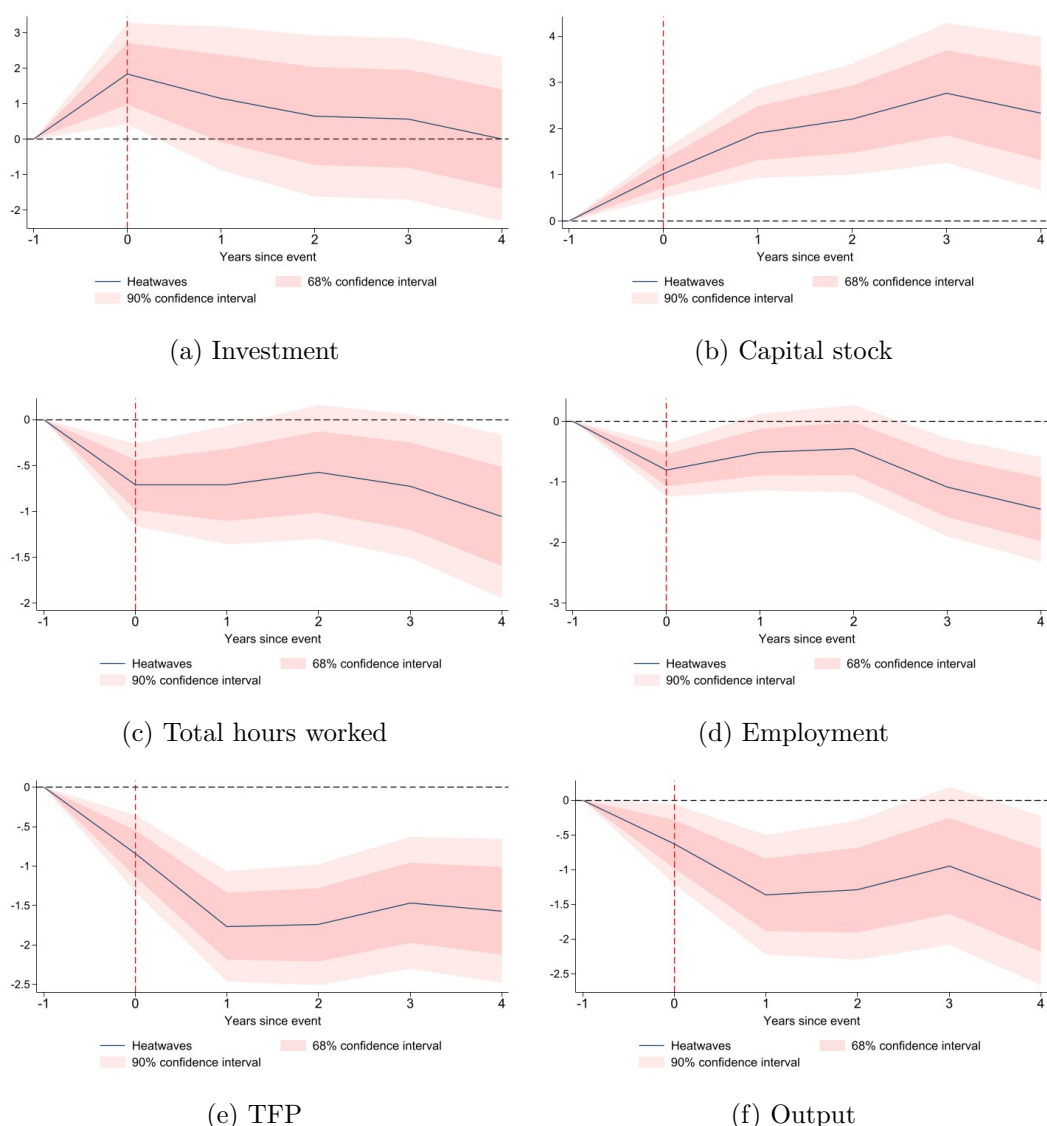
## 4.2 Impact on medium-run output growth and its components

### 4.2.1 Heatwaves

Turning to the medium-term impacts, we find a significant negative impact of summer heatwaves on regional output for a number of years following the event (Figure 5). After four years, regional

output is 1.4 percentage points lower. In the year of the event itself, there is a negative impact on employment and hours worked, consistent with the literature finding workers work less on hotter days (see, for example [Heal and Park, 2016](#)). Capital increases significantly over the medium term, but TFP falls. Lower TFP could be explained either by lower efficiency of workers from the higher temperatures or greater use of adaptation capital, such as air conditioning, which reduces the impact of hotter temperatures on workers but is otherwise less productive.

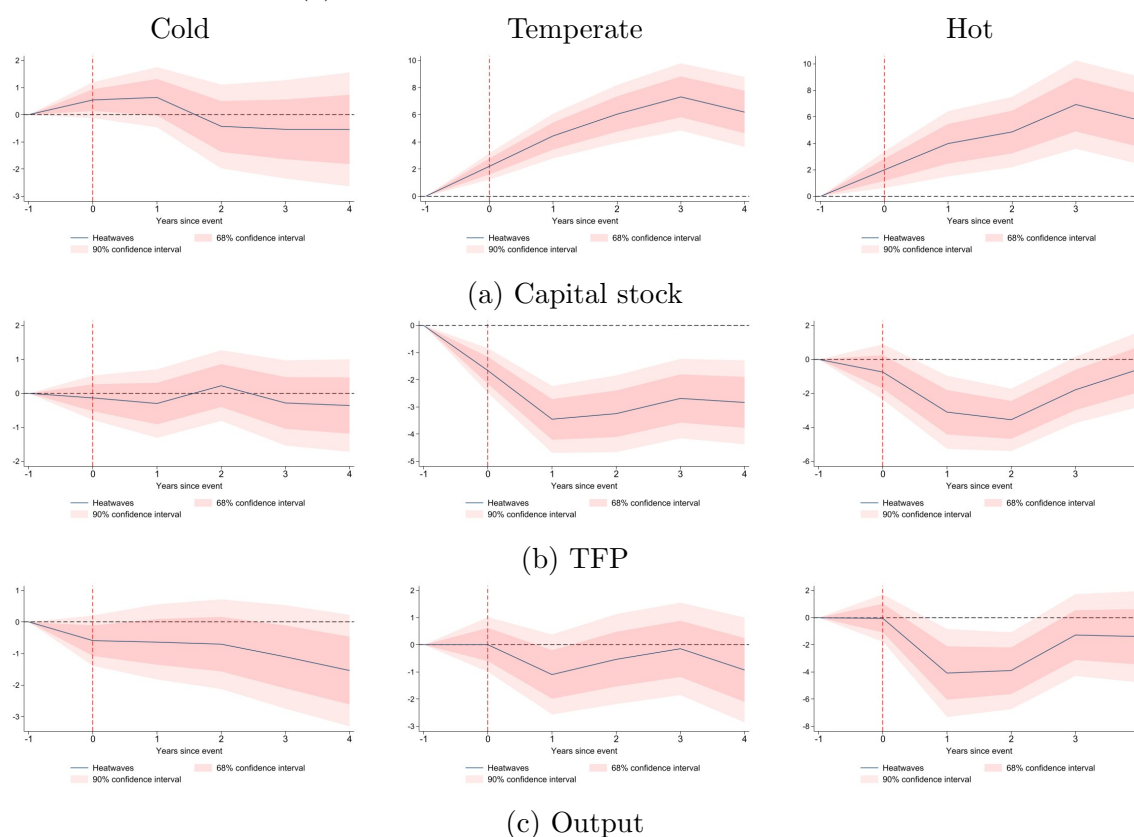
Figure (5) Summer heatwave growth accounting (all regions)



Note: Figure 5 shows medium-term effects of summer heatwaves on components of regional potential output of all regions. Heatwaves are defined as deviations of seasonal temperature from the historical mean (1991-2020) above the 1.5 degree Celsius threshold. The X-axis shows the years after the shock in period 0, and the y-axis shows the percentage change in a variable.

In the next step, we explore the impact of heatwaves across different types of regions. To capture non-linear effects, we first estimate how the regional impact varies across regions based on their historical average climate. We observe that the adaptation impact described above occurs in temperate and hot regions, with capital increasing, but TFP falling in both regional groupings (Figure 6).<sup>1</sup> There is far less evidence of investment in adaptation in cold regions, although total hours worked significantly decreases.

Figure (6) Summer heatwave impact by baseline climate



Note: Figure 6 shows medium-term effects of summer heatwaves on components of regional potential output, with regions split by historic average climate. Heatwaves are defined as deviations of seasonal temperature from the historical mean (1991-2020) above the 1.5 degree Celsius threshold. The X-axis shows the years after the shock in period 0, and the y-axis shows the percentage change in the variable.

There is also a stark contrast between the effects in inland and coastal regions (see Figures A6 and A7 in the Appendix). There is clear evidence of adaptation expenditure for inland regions: capital increases, TFP falls, and output falls overall. For coastal regions, there is no significant impact on capital or employment, and TFP increases somewhat. It is possible that access to the sea (or to the sea breeze) may help reduce the impact on labour efficiency. There

<sup>1</sup>Full growth accounting results can be found in figures A1 to A3 in the Appendix.

may also be support for tourism.

To understand the dynamic impacts across different industries, we revisit the impact of each disaster on gross value added (GVA) by NACE sector. Data are available at NUTS-3 level for 10 groups of NACE sectors, which we further aggregate into four main groups: agriculture, manufacturing, construction, and services.<sup>2</sup>

We observe that heatwaves negatively affect the agricultural sector GVA, most likely by reducing crop yields and worsening livestock conditions. The impact on manufacturing is initially adverse but positive later, which might be due to the impact on labour efficiency, followed by higher output as firms and households put in place adaptations to mitigate and improve resilience. Heatwaves may also negatively impact the public sector by affecting human health and increasing operational costs for public services like the health care system. An increase in health care costs can lead to an increase in insurance payouts, thereby negatively affecting the business services, as described in Colacito et al. (2019).

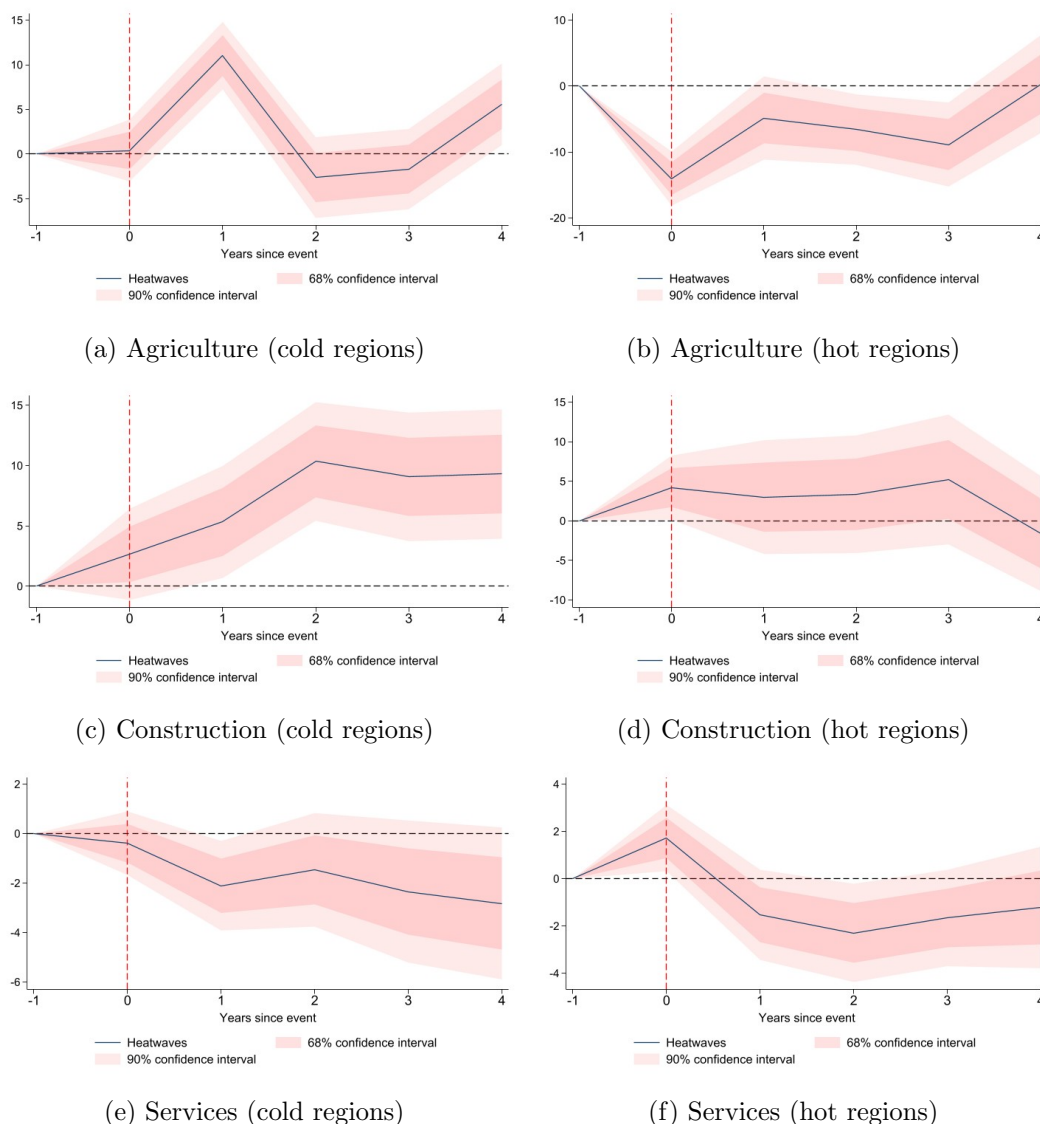
Figure (7) Impact of heatwaves on sectoral gross value added



Note: Figure 7 shows medium-term effects of heatwaves on gross value added of NUTS-3 regions by sector. Heatwaves are defined as deviations of seasonal temperature from the historical mean (1991-2020) above the 1.5 degree Celsius threshold. The X-axis shows the years after the shock in period 0, and the y-axis shows the percentage change in gross value added of the specific sector. For details on sector classification, see Table A1.

<sup>2</sup>For classification details, see Table A1 in the Appendix

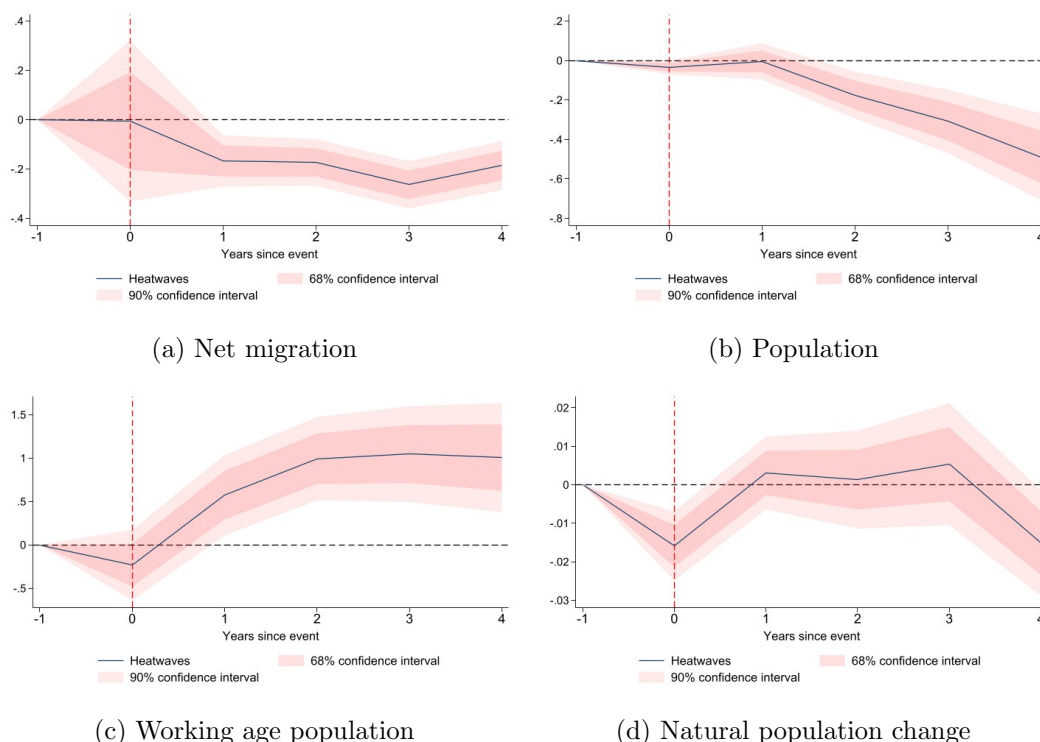
Figure (8) Impact of heatwaves on sectoral gross value added in hot versus cold regions



Looking at the differential impact across hot and cold regions, summer heatwaves significantly reduce agricultural production in hot regions as higher temperatures may affect agricultural yield and contribute to soil degradation in the long term (Figure 8). By contrast, the significant positive impact in the cold regions comes with a lag, which might be because moderate temperatures improve growing conditions. In the construction sector, hot regions face a decline in production, while cold regions show an increase. The impact on other sectors does not vary across hot and cold regions. However, long-term detrimental effects, especially on the service sector, become dominant in the medium run. By contrast, the significant decline in services in hot regions contributes to an overall decline in economic output. Turning to population dynam-

ics, we identify a significant decrease in net inward migration and a fall in overall population (Figure 9). Nonetheless, there is a significant increase in the working-age population, suggesting those leaving may predominantly be economically inactive compared to those arriving. Given aggregate hours worked and employment falls, there is likely a fall in participation or increased unemployment.

Figure (9) Demographic impact of heatwaves (all regions)



Note: Figure 9 shows medium-term effects of summer heatwaves on demographic transitions of all regions. Heatwaves are defined as deviations of seasonal temperature from the historical mean (1991-2020) above the 1.5 degree Celsius threshold. The X-axis shows the years after the shock in period 0, and the y-axis shows the percentage change in a variable.

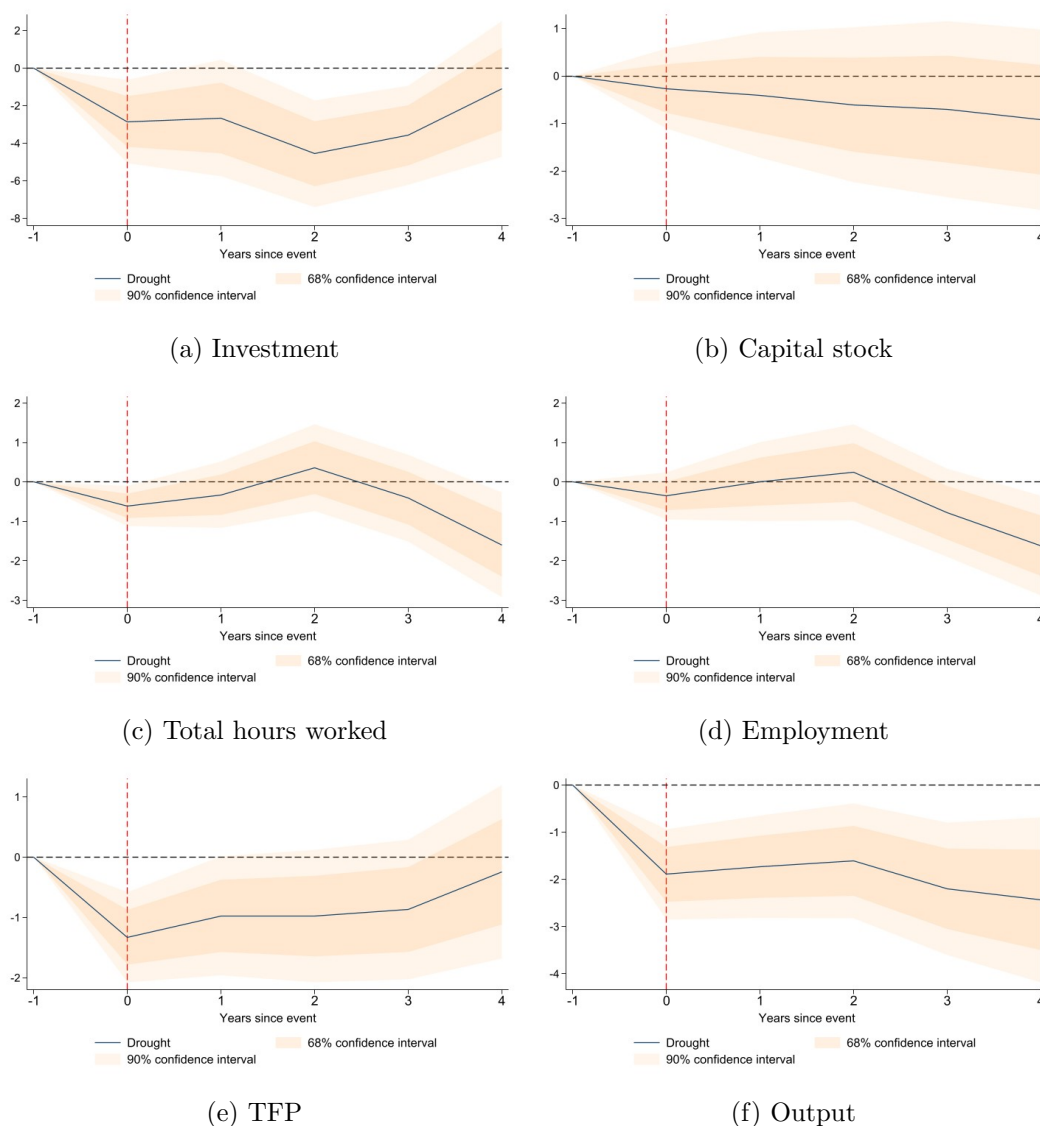
## 4.2.2 Droughts

While the panel regression on the short-term impact of droughts found no significant impact (Table 4.1), the LP-DiD does find a sizeable impact in the near term. This difference likely arises through the implementation of clean treatments and controls, where the effect of confounding events are removed. For droughts, these confounding events include heatwaves and recurring multi-year droughts. Moreover, we find the negative impact to both persist and grow over the medium term (Figure 10). Four years after having been affected by the drought, regional output is 2.4 percentage points lower. This may indicate that the effects of a drought may develop



gradually and have persistent negative effects. In contrast to heatwaves, however, there is no significant impact on the capital stock over the entire horizon. Both investment and TFP are lower for a number of years before returning in line with the control regions. There is also an immediate decline in total hours and total employment, which strengthens towards the end of the horizon. As with heatwaves, there is a fall in TFP, pointing to a likely reduction in agricultural output as well as likely investment in adaptation, such as irrigation.

Figure (10) Droughts growth accounting (all regions)

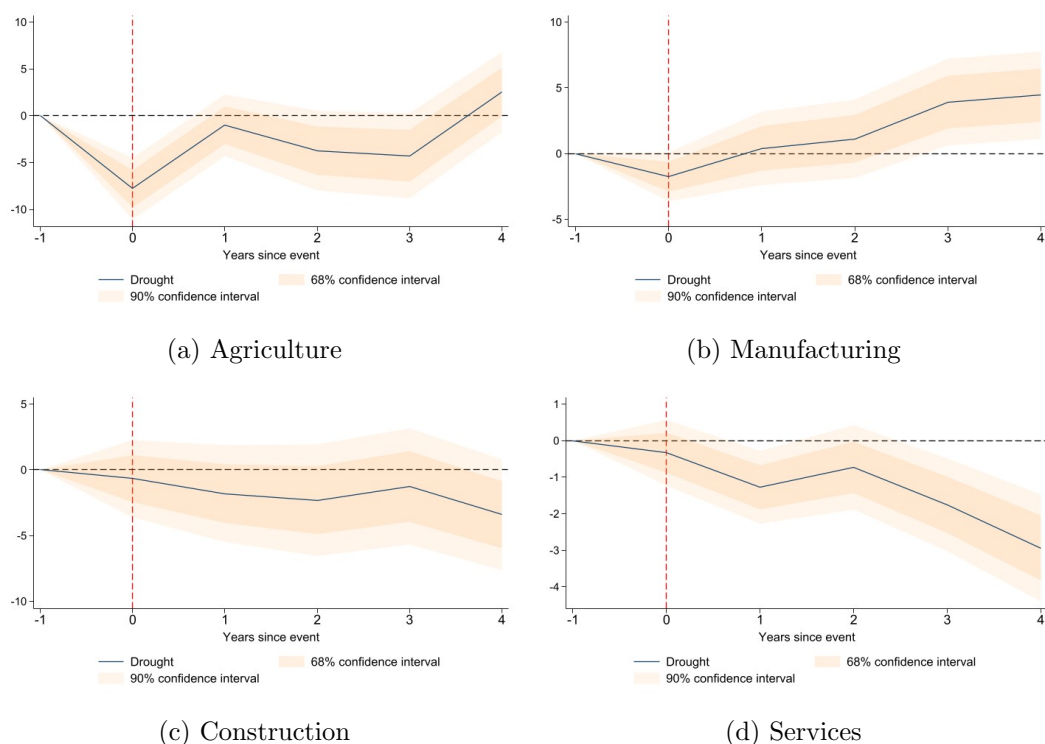


Note: Figures 10 shows medium-term effects of droughts on regional components of potential output of all regions. The drought event is a binary variable that takes the value 1 if a region for three consecutive months has total monthly precipitation less than 50 percent of the historical mean of monthly precipitation (1991-2020). The X-axis shows the years after the shock in period 0, and the y-axis shows the percentage change in a variable.

Looking at region characteristics, we find that droughts negatively affect both urban and rural regions significantly in the near term (see Figures A13 & A14). The impact is persistent for the urban regions. We also observe a persistent medium-run negative impact on the labour market through declining total hours worked and total employment towards the end. In rural regions, productivity significantly declines in the near term, unlike in urban regions.

Droughts adversely affect GVA in the agriculture sector, where output remains persistently below its initial level until it returns after four years. This likely reflects reduced crop efficiency and perhaps higher input costs, such as irrigation and livestock feed. Service sector output falls. Since rates of adaptation may differ between regions, we also investigate the impact in low and high-income regions.

Figure (11) Impact of droughts on sectoral gross value added

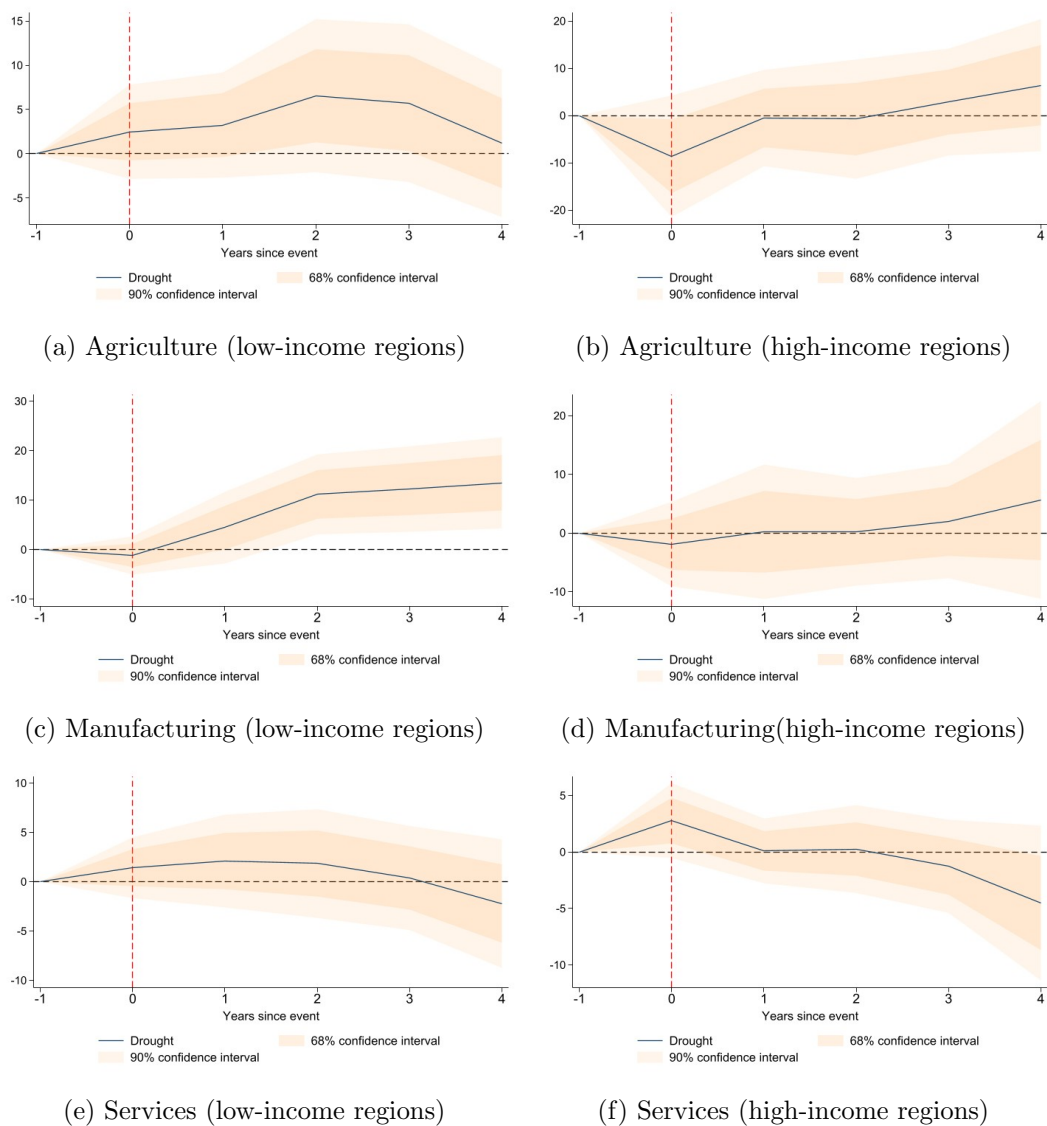


Note: Figure 11 shows medium-term effects of droughts on gross value added of NUTS-3 regions by sector. The drought event is a binary variable that takes the value one if a region for three consecutive months has total monthly precipitation less than 50 percent of the historical mean of monthly precipitation (1991-2020). The X-axis shows the years after the shock in period 0, and the y-axis shows the percentage change in gross value added of the specific sector. For details on sector classification, see Table A1.

Next, we explore the impact of droughts on the GVA of various sectors across low and high-income regions (See Figure 12). We observe the contemporaneous impact on agricultural production for low-income regions, which may be caused by limited resources like irrigation

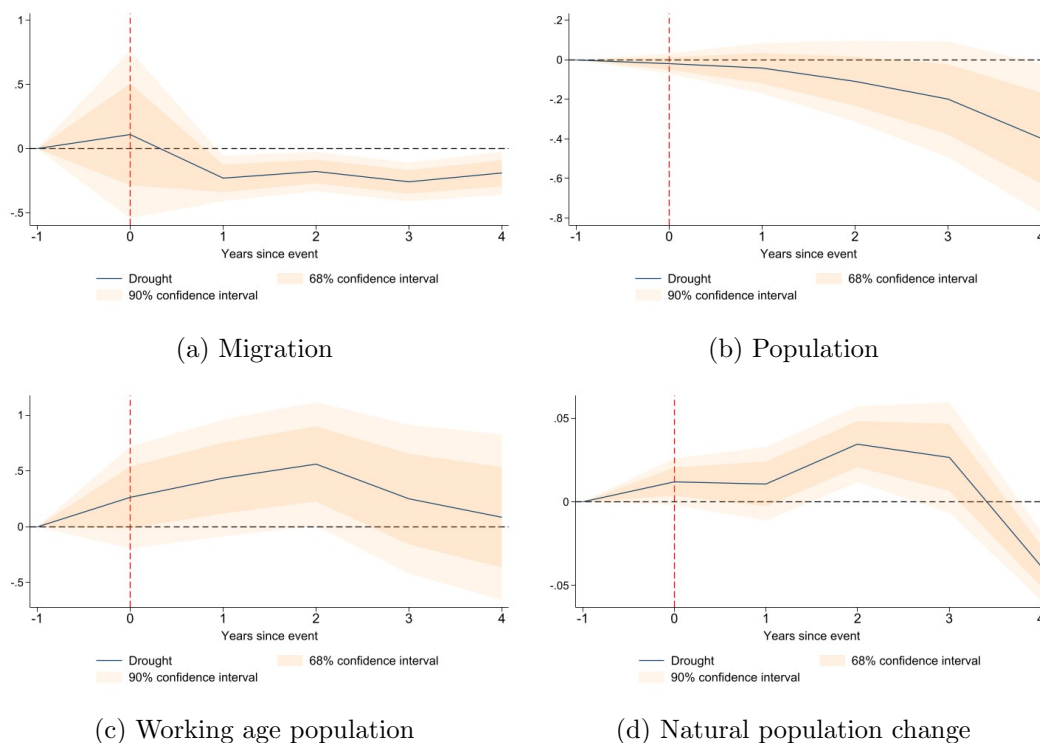
systems, given that the impact on agriculture in high-income regions is insignificant. By contrast, the impact on services is more marked in high-income regions.

Figure (12) Impact of droughts on sectoral gross value added in low versus high-income regions



Similar to heatwaves, we find that droughts result in a significant fall in inward net migration to the affected region, which persists for the entire four-year period post-event (Figure 13). By the end of the fourth year following the drought, the region's population is around four percent lower.

Figure (13) Demographic impact of droughts (all regions)

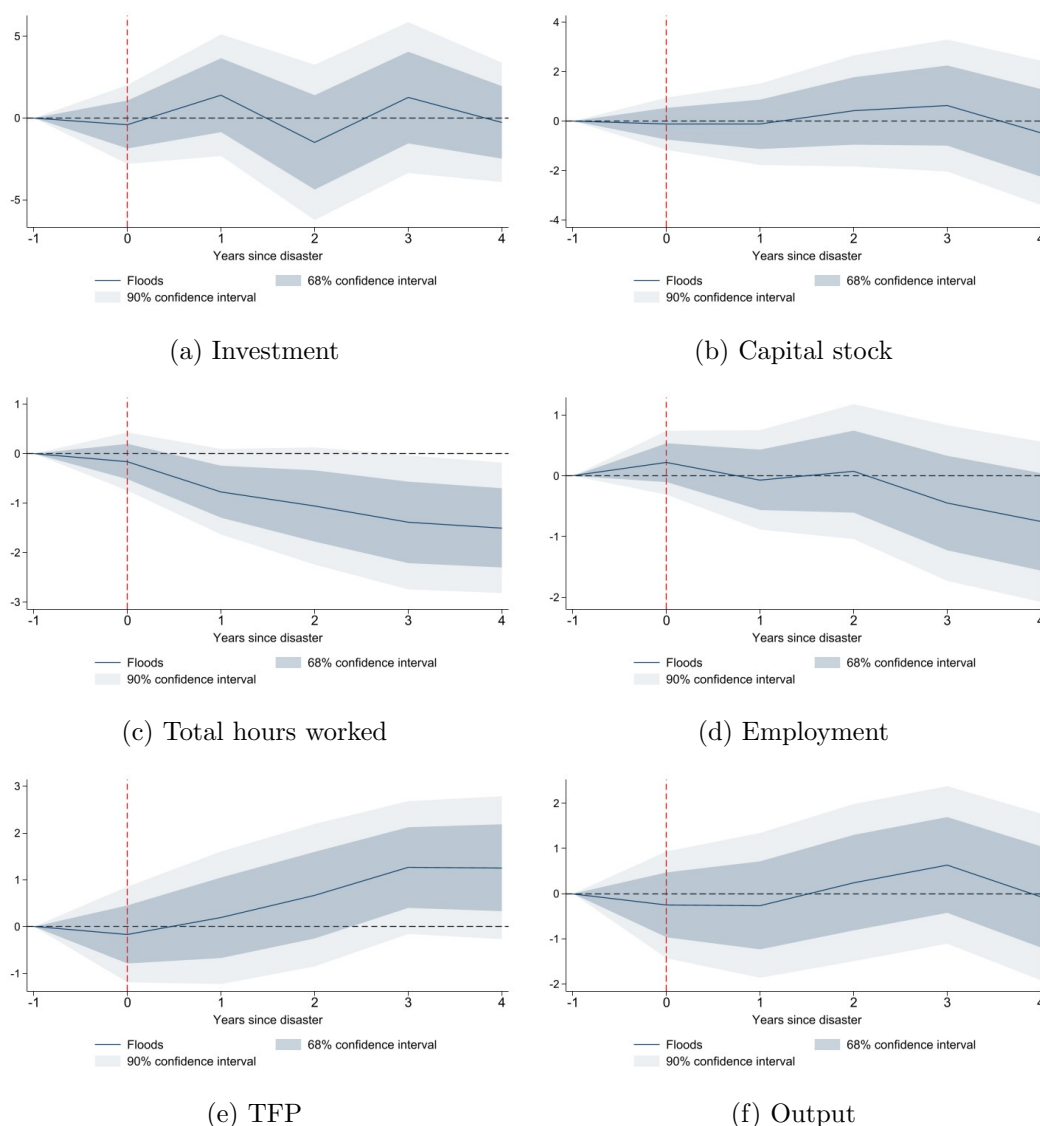


Note: Figure 13 shows medium-term effects of droughts on regional components of potential output for all regions. The event of drought is a binary variable that takes the value 1 if a region, for three consecutive months, has total monthly precipitation less than 50 percent of the historical mean of monthly precipitation (1991-2020). The x-axis shows the years after the shock in period 0 and the y-axis shows the percentage change in the variable.

### 4.2.3 Floods

Similarly to the case of droughts, Table 4.1 shows that we do not find an effect of floods on output on impact (Figure 14). Likewise, the impact through capital is insignificant. Investment, employment and TFP are all flat and insignificant in our estimates. However, there is a consistent decline in total hours worked. That lack of aggregate impact may at first glance appear counterintuitive. Floods are destructive and can initially reduce capital in affected regions. Disruption and management distraction caused by reconstruction could similarly lower output in the years immediately following the event. However, in the medium term, the rebuild provides opportunities to renew capital and could lead to higher output. [Leiter et al. \(2009\)](#), for example, find floods in certain European regions can boost the output and capital of firms, partly due to reconstruction efforts after the disasters strike.

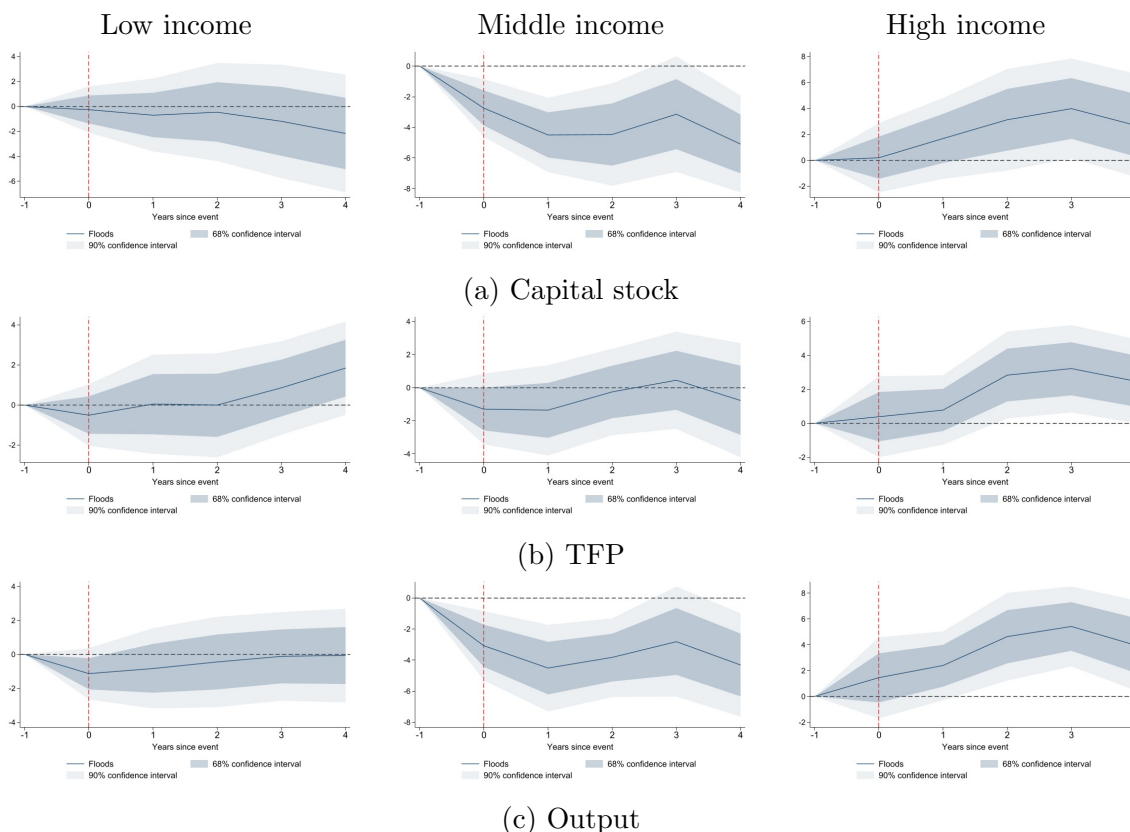
Figure (14) Floods growth accounting (all regions)



Note: Figure 14 shows medium-term effects of floods on components of regional potential output of the entire sample. The event of a flood is a binary variable that takes the value 1 if the standardised precipitation index for at least once in a month shows extremely wet conditions. The X-axis shows the years after the shock in period 0, and the y-axis shows the percentage change in a variable.

But this aggregate impact masks divergences between types of regions. In middle-income regions, investment falls significantly over the medium term (Figure 15). This is in contrast to high-income regions, where it increases significantly in the years following the event. This suggests that the ability of regions to recover from events and carry out reconstruction activity depends on income and likely (although not studied here) access to finance. Similarly, we observe a significant increase in the output of urban regions after the floods which can be explained by increasing investment and capital stock that attract more employment and improve productivity

Figure (15) Flood impact by income level

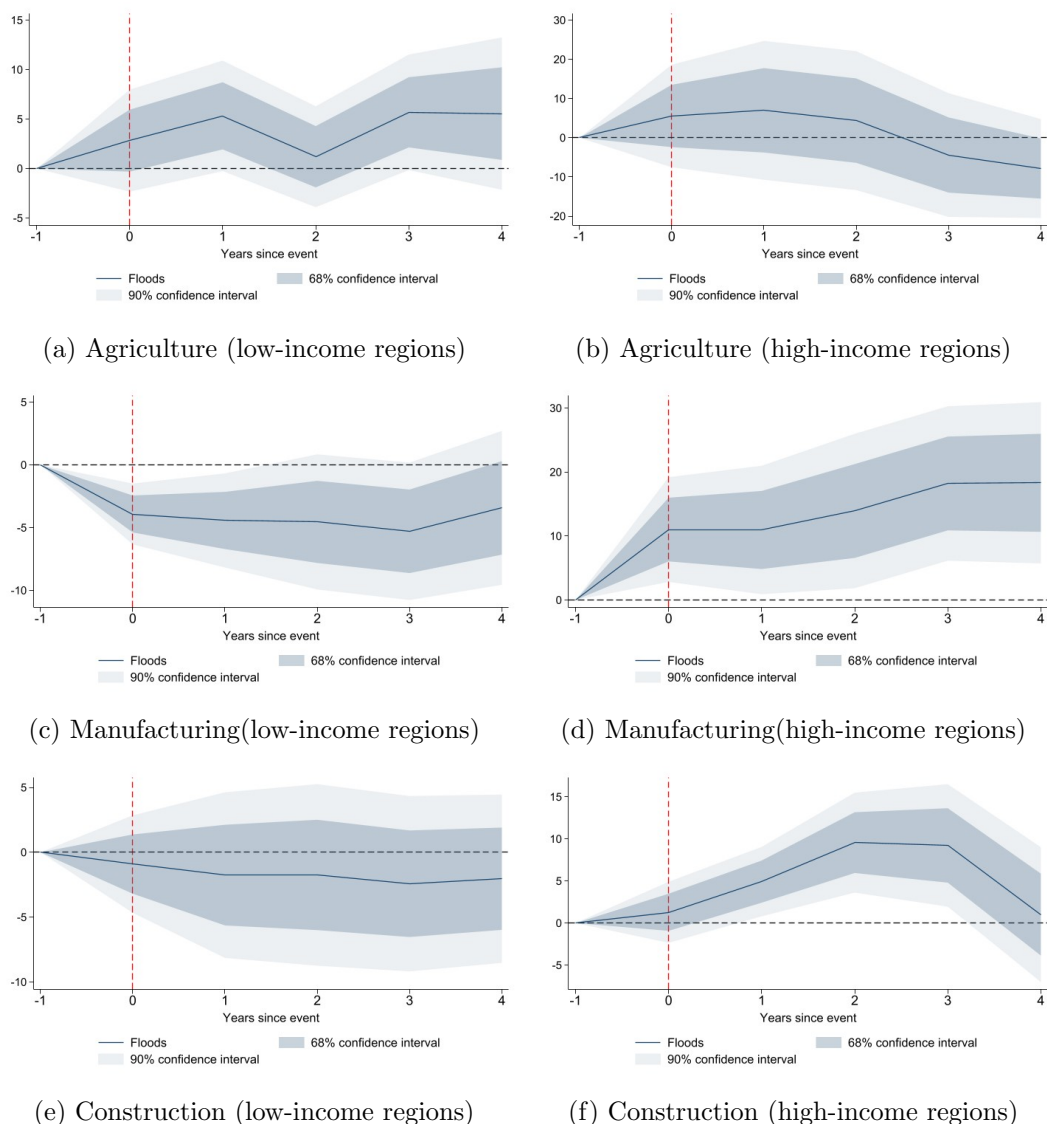


Note: Figure 6 shows medium-term effects of floods on components of regional potential output, with regions split by income per capita. The event of a flood is a binary variable that takes the value 1 if the standardised precipitation index for at least one month shows extremely wet conditions.. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

(Figure A28).

We do not find significant sectoral impacts of floods when grouping together all affected regions, but there are notable differences between low and high-income regions. There is a significant decline in manufacturing sector activity in low-income regions while in high-income regions, manufacturing activity is significantly higher. The contemporaneous impact on the construction sector is not significant across the two types of regions, but the trend shows that construction output increases in high-income regions in the following years, which is absent in low-income regions. This increased manufacturing and construction activity in only high-income regions supports the narrative of reconstruction activity being reliant on sufficient access to finance.

Figure (16) Impact of floods on sectoral gross value added in low versus high-income regions

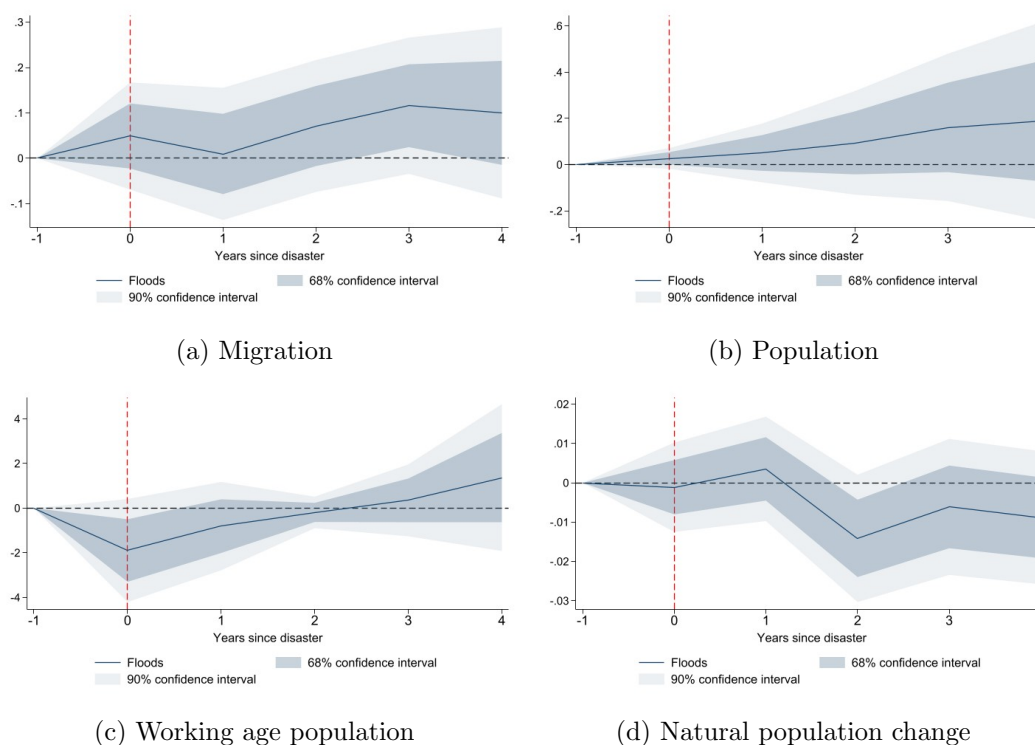


Note: Figure 16 shows medium-term effects of floods on gross value added of NUTS-3 regions by sector in high versus low-income regions. The event of a flood is a binary variable that takes the value one if the standardised precipitation index for at least once in a month shows extremely wet conditions. The X-axis shows the years after the shock in period 0, and the y-axis shows the percentage change in gross value added of the specific sector. For details on sector classification, see Table A1.

In contrast to the findings for heatwaves and droughts, there are no significant demographic effects following floods (Figure 17). In contrast to these former types of extreme events, the reconstruction activity and increases in manufacturing and construction may provide incentives to remain within the region.



Figure (17) Demographic impact of floods (all regions)



Note: Figure 17 shows medium-term effects of droughts on regional components of potential output for all regions. The event of drought is a binary variable that takes the value 1 if a region, for three consecutive months, has total monthly precipitation less than 50 percent of the historical mean of monthly precipitation (1991-2020). The x-axis shows the years after the shock in period 0 and the y-axis shows the percentage change in the variable.

## 5 Conclusion

We analyse the impacts of extreme climate events, encompassing heatwaves, floods and droughts, on the regional economic output of EU Member States. We also undertake a growth accounting exercise to understand the drivers of potential output over the medium term. We establish persistent impacts in all three main components of potential output – capital, labour and total factor productivity – although the impacts do vary by type of extreme event and by other regional characteristics such as historical climatic conditions and income.

What is striking about our findings is that the impact of an extreme event may not only persist but can also intensify over time. A simplistic view of an extreme event being characterised as an initial destructive and disruptive shock followed by rehabilitation and reconstruction seems poorly supported by this evidence. A better characterisation would appear to be that income losses and disruption can depress demand, and that lower activity and employment can persist,

and endogenously lower medium-term output. Overall, four years after the event, output is 1.4 percentage points lower in regions affected by a heatwave, and 2.4 percentage points lower in regions affected by a drought. Given that our selection of clean treatment and clean controls excludes multi-year droughts, heatwaves and droughts coinciding and repeated events, these figures likely underestimate the full impact of extreme events on output.

The almost certain increase in frequency and magnitude of such climate events in the coming decades is likely, therefore, to exacerbate existing economic challenges surrounding productivity and demographics. We uncover evidence of adaptation spending following heatwaves. Capital increases in affected regions, but since adaptation capital is less productive than other types of capital in aggregate, total factor productivity falls. Moreover, we document the falling population in affected regions. To the extent that these impacts are more likely to occur in certain countries, there may well be migratory pressures within Europe itself, to say nothing of the political pressures arising from inward migration from regions of the world more heavily affected by climate change.

Yet the impacts are not universally negative for potential output. We also find evidence that economic activity may be higher following an extreme climate event, although this appears to be restricted to just one case: floods occurring in high-income regions. The destruction of capital leads to a period of reconstruction, including higher output and TFP, suggesting these regions are able to “build back better” and upgrade their capital. But floods in less wealthy regions do not see this benefit, with output and TFP unchanged or lower. This suggests access to financial support through wealth, insurance, or credit may be critical to providing positive benefits.

These insights underscore the need for targeted adaptation strategies at regional level to ensure timely and successful recoveries and to mitigate the adverse impacts on productivity and demographics. In the absence of effective Europe-wide policies, more frequent extreme climate events could lead to prolonged impacts in affected regions, which could in turn exacerbate the divergence in regional economic outcomes.

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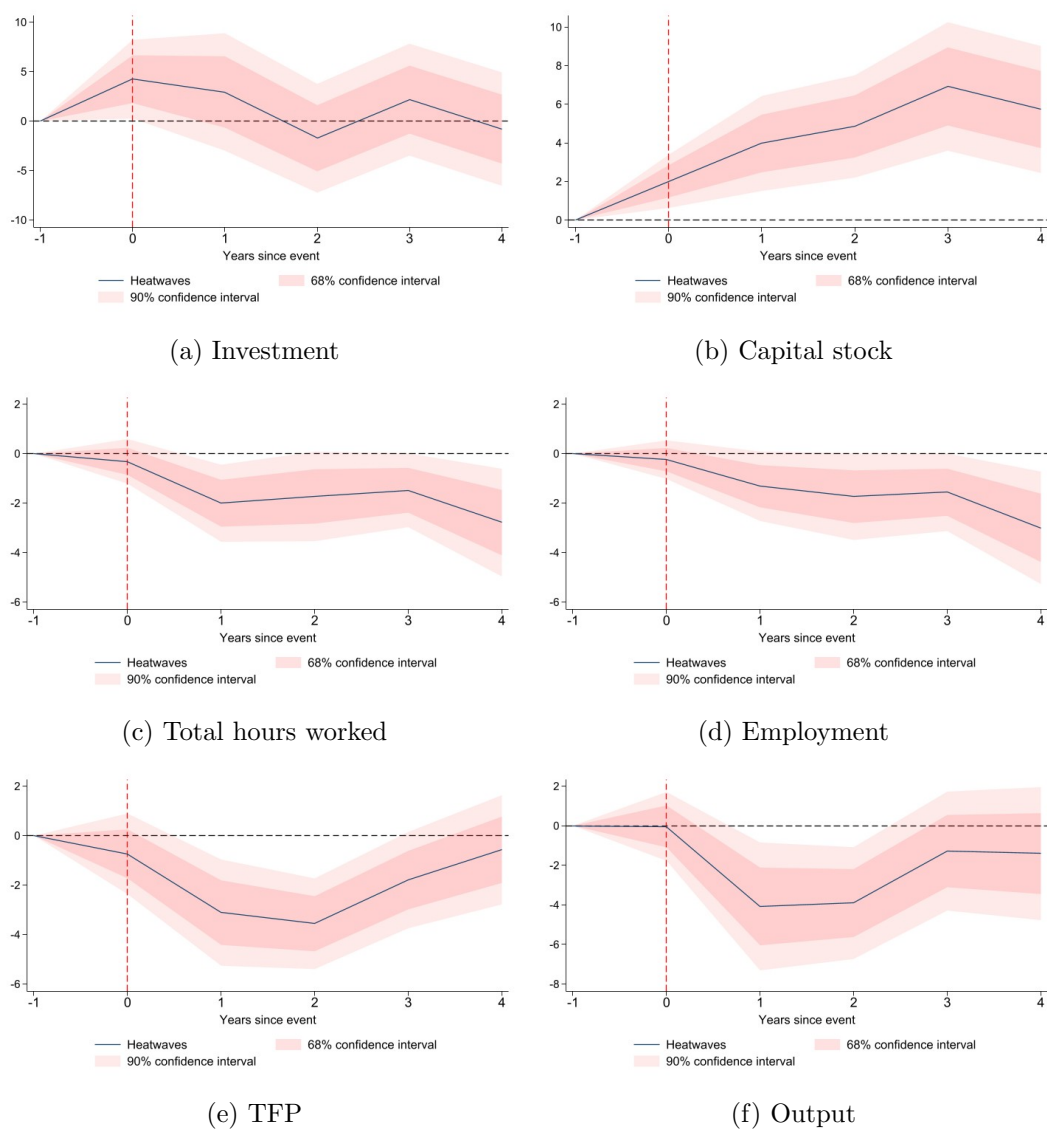
## A Appendix

Table (A1) Classification of broad sectors using NACE sector groupings

Sector	Industries
Agriculture	Agriculture, forestry and fishing
Manufacturing	Manufacturing Mining and quarrying Electricity, gas, steam and air conditioning supply Water supply; sewerage, waste management and remediation activities
Construction	Construction
Services	Wholesale and retail trade; repair of motor vehicles and motorcycles Transportation and storage Accommodation and food service activities Arts, entertainment and recreation Activities of households as employers Activities of extraterritorial organisations and bodies Public administration and defence; compulsory social security Education Human health and social work activities Information and communication Financial and insurance activities Real estate activities Professional, scientific and technical activities Administrative and support service activities

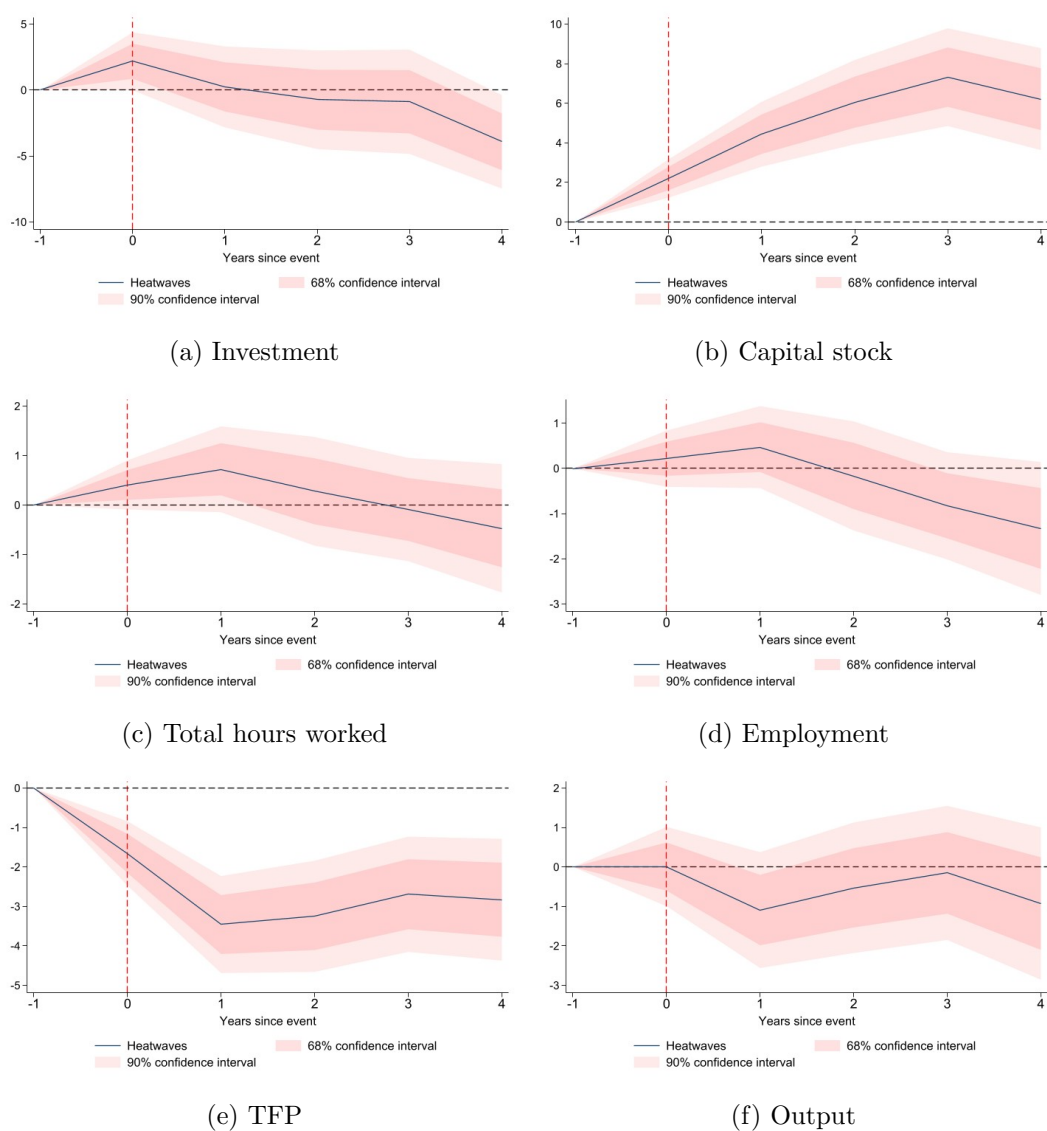
Note: table A1 organises broad sectors of the economy according to NACE sector groupings. For our analysis, we have categorised the sectors into four main categories including agriculture, manufacturing, construction and services. Source: [European Commission \(2024\)](#)

Figure (A1) Summer heatwave growth accounting (hot regions)



Note: Figure A1 shows medium-term effects of summer heatwaves on components of regional potential output of hot regions. Heatwaves are defined as deviations of seasonal temperature from historical mean (1991-2020) above 1.5 degree Celsius threshold. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

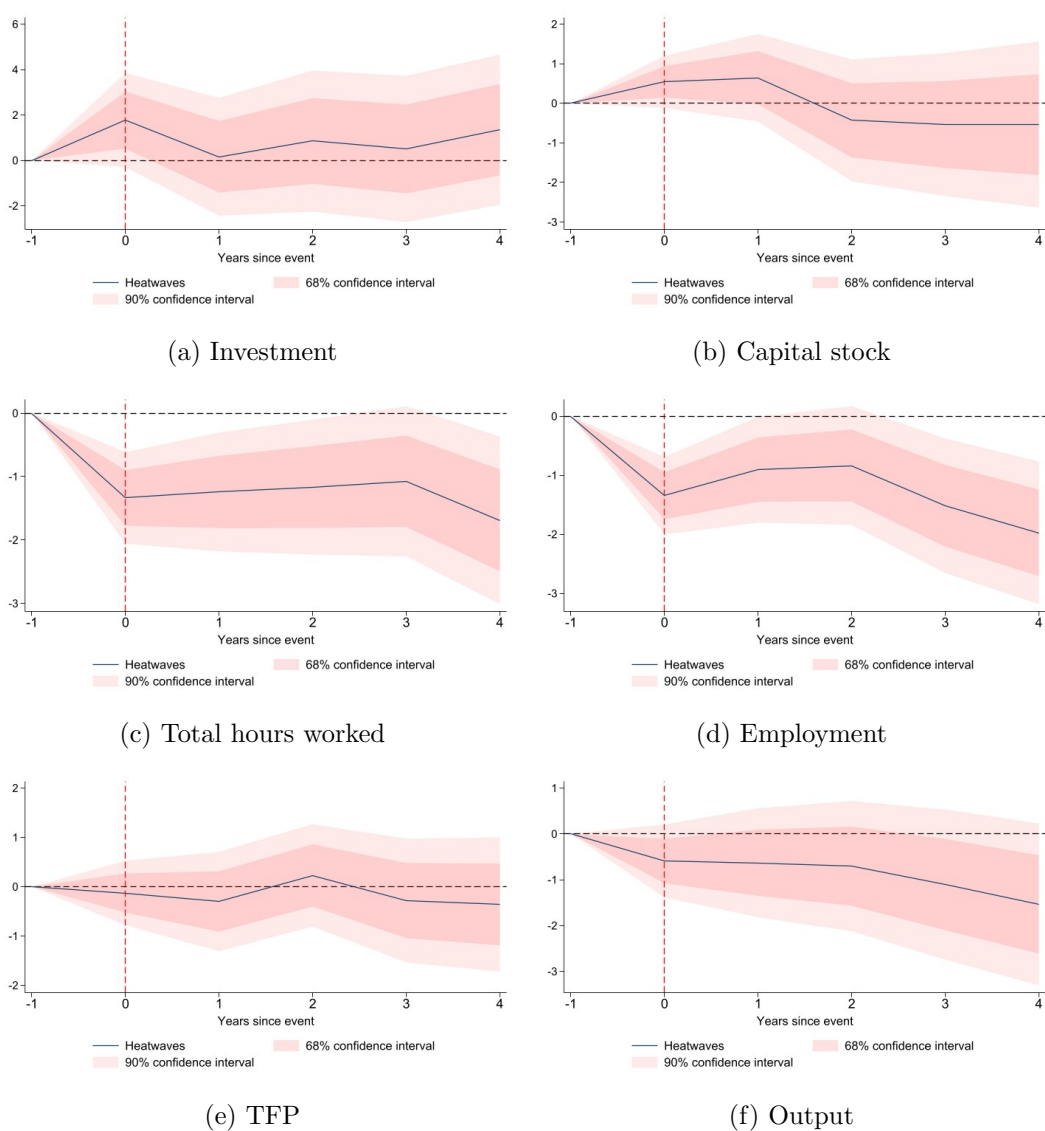
Figure (A2) Summer heatwave growth accounting (temperate regions)



Note: Figure A2 shows medium-term effects of summer heatwaves on components of regional potential output of temperate regions. Heatwaves are defined as deviations of seasonal temperature from historical mean (1991-2020) above 1.5 degree Celsius threshold. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

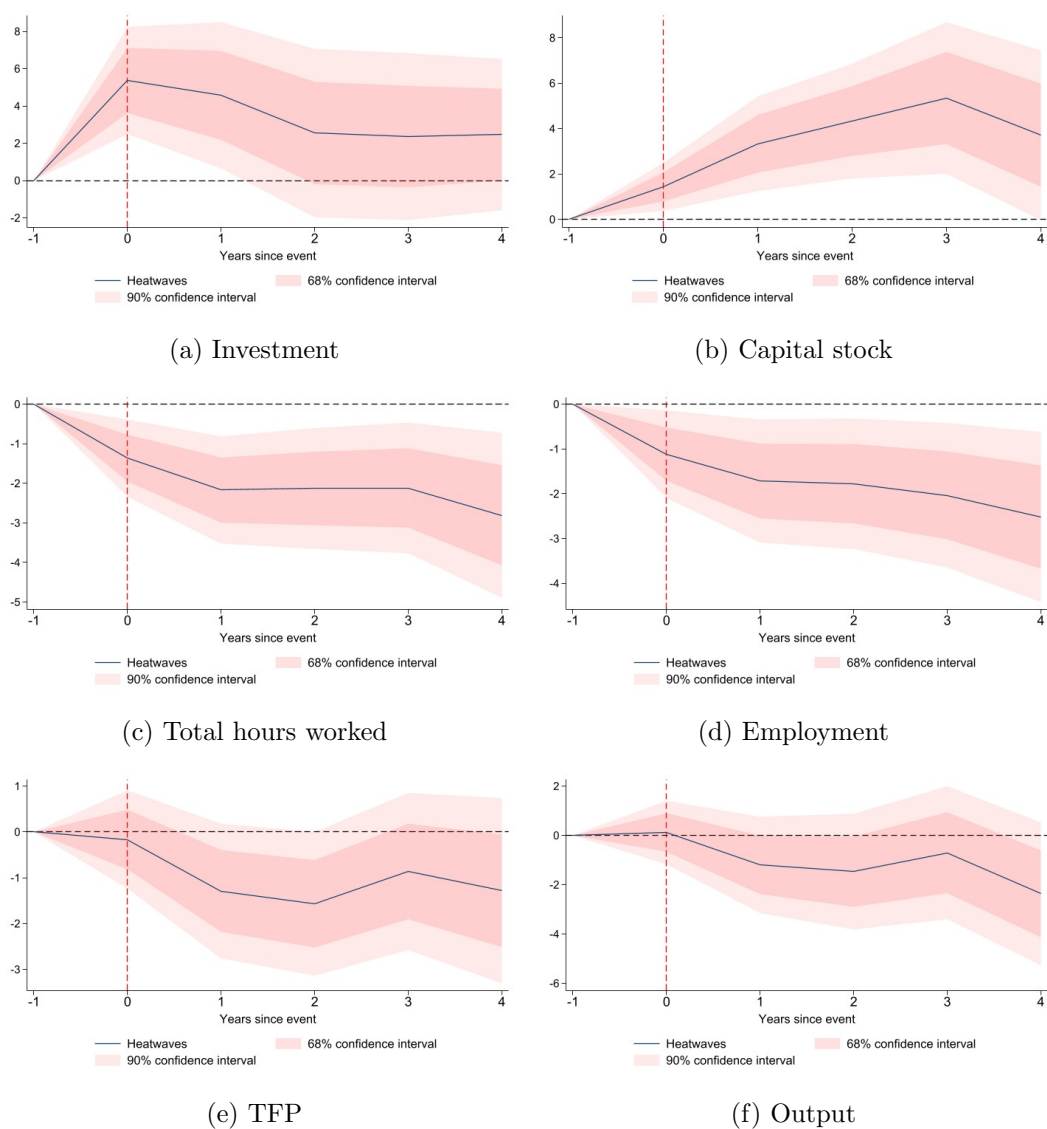


Figure (A3) Summer heatwave growth accounting (cold regions)



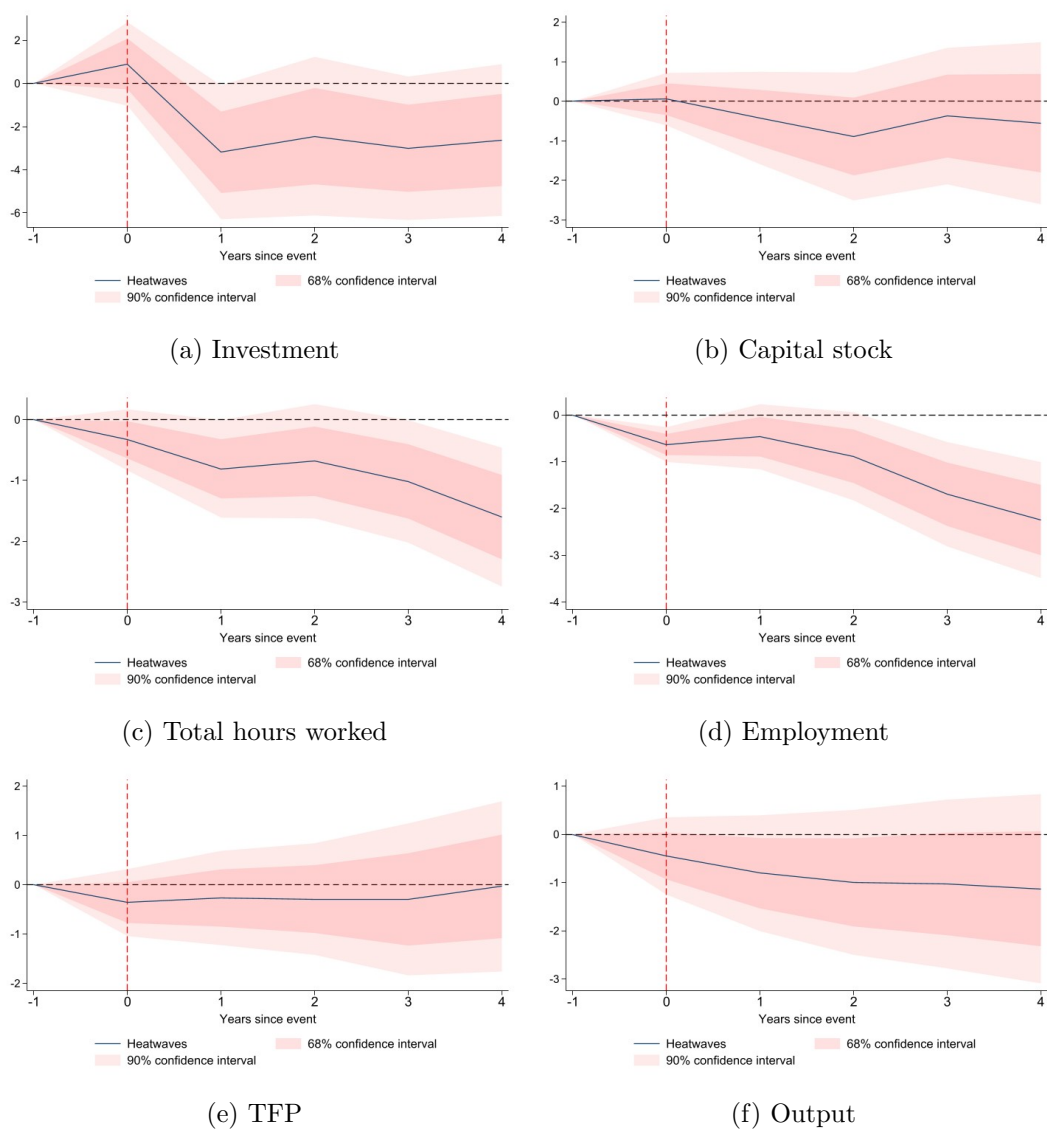
Note: Figure A3 shows medium-term effects of summer heatwaves on components of regional potential output of cold regions. Heatwaves are defined as deviations of seasonal temperature from historical mean (1991-2020) above 1.5 degree Celsius threshold. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A4) Summer heatwave growth accounting (low-income regions)



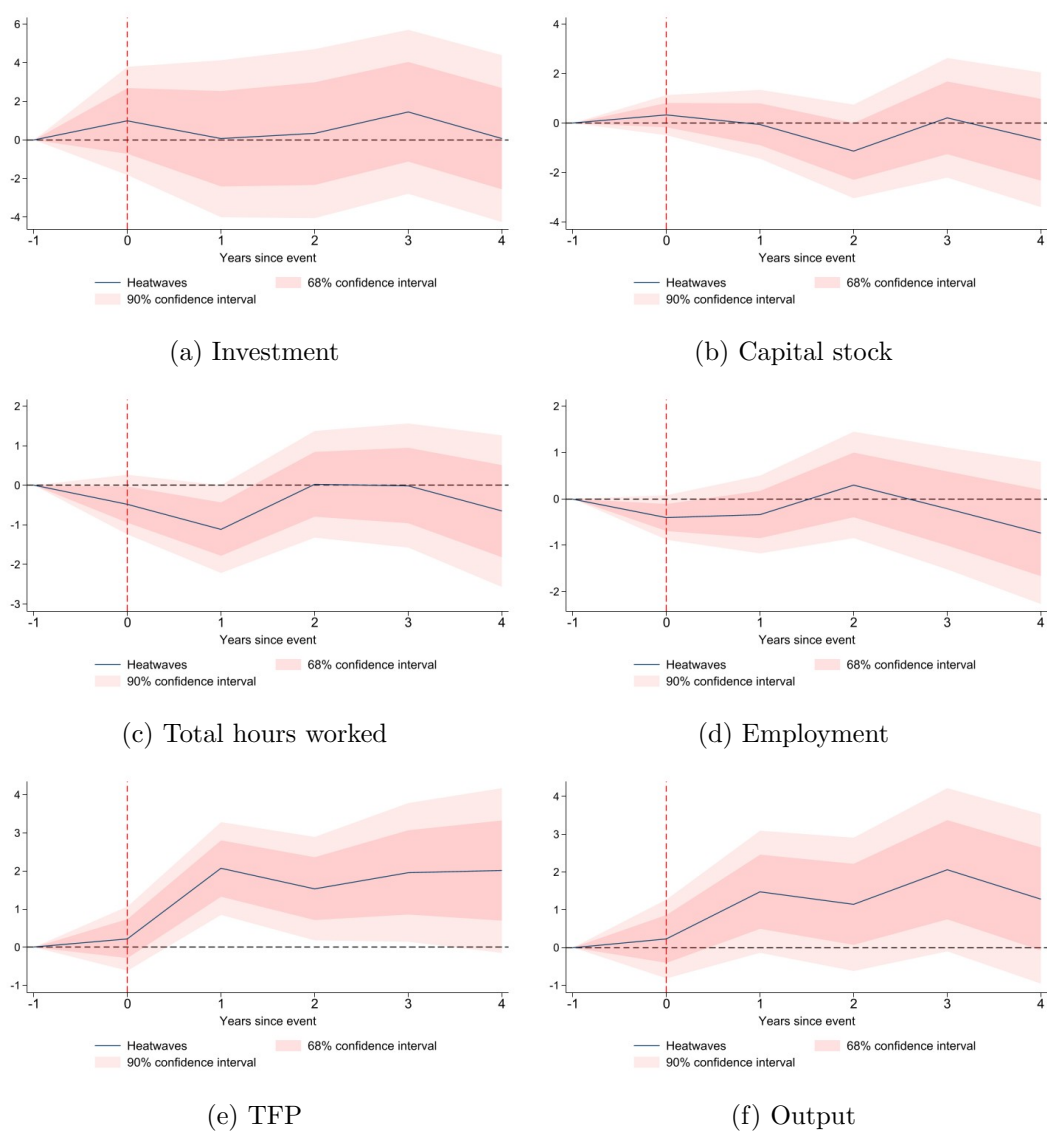
Note: Figure A4 shows medium-term effects of summer heatwaves on components of regional potential output of low-income regions. Heatwaves are defined as deviations of seasonal temperature from historical mean (1991-2020) above 1.5 degree Celsius threshold. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A5) Summer heatwave growth accounting (high-income regions)



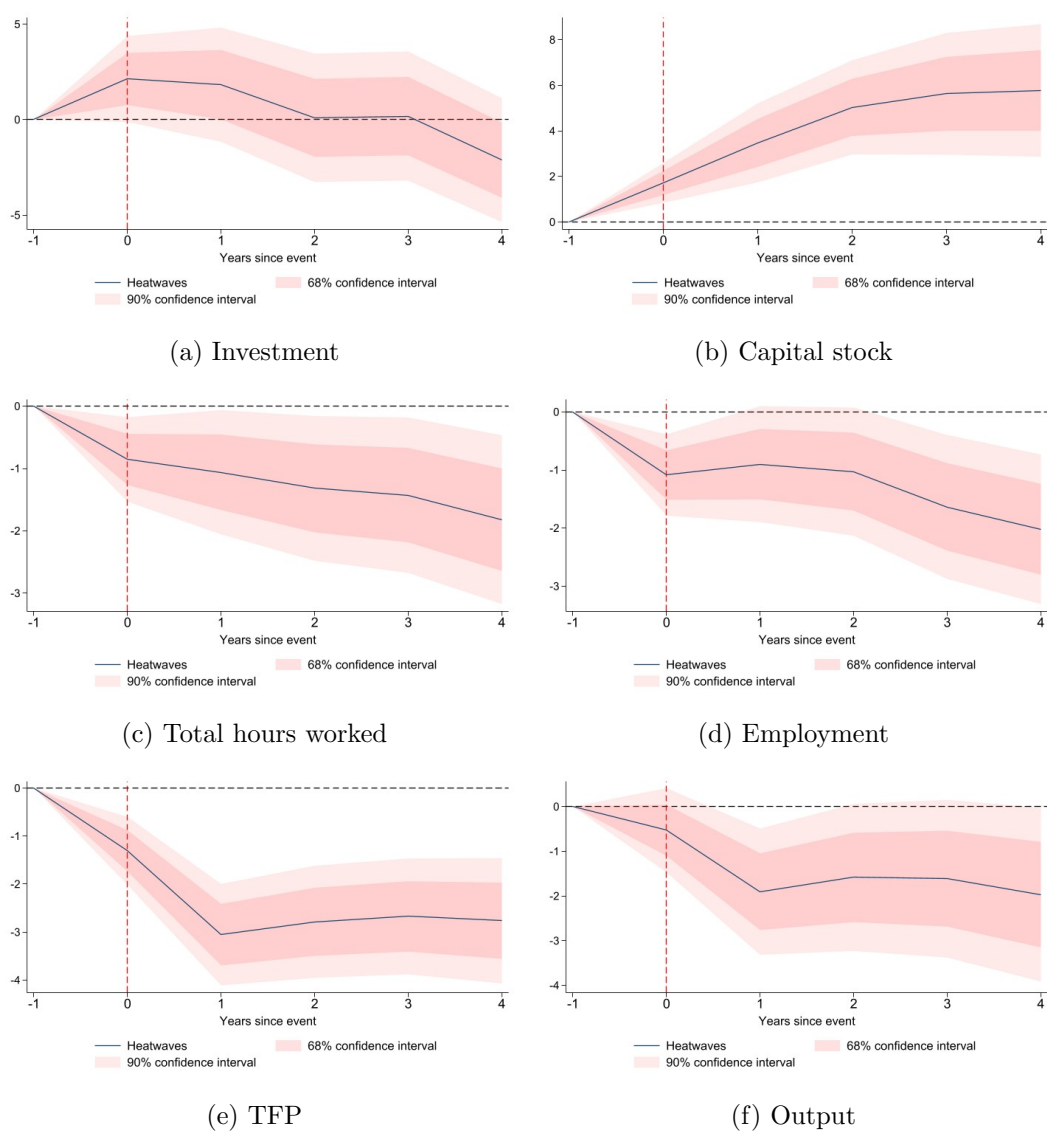
Note: Figure A5 shows medium-term effects of summer heatwaves on components of regional potential output of high-income regions. Heatwaves are defined as deviations of seasonal temperature from historical mean (1991-2020) above 1.5 degree Celsius threshold. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A6) Summer heatwave growth accounting (coastal regions)



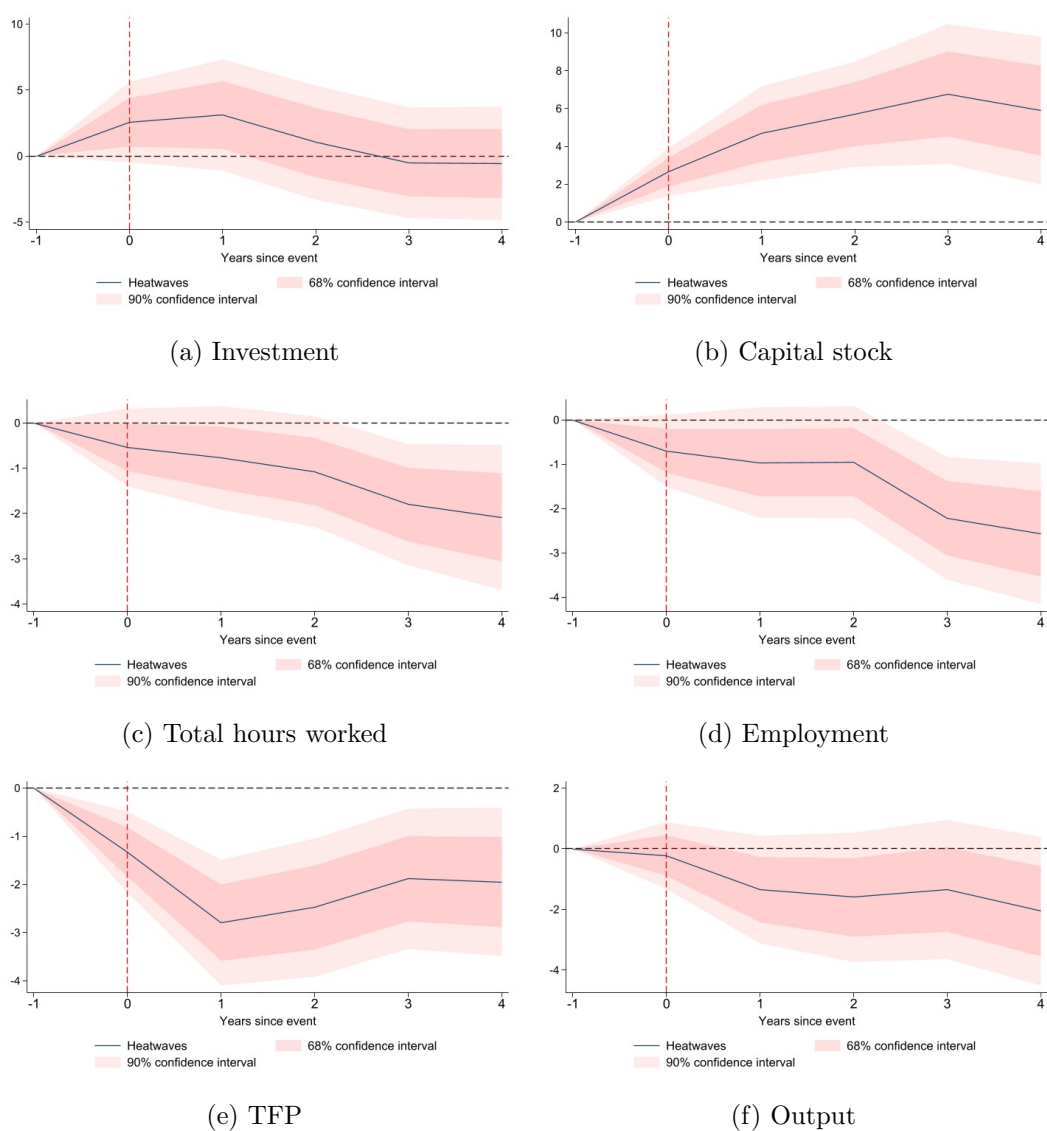
Note: Figure A6 shows medium-term effects of summer heatwaves on components of regional potential output of coastal regions. Heatwaves are defined as deviations of seasonal temperature from historical mean (1991-2020) above 1.5 degree Celsius threshold. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A7) Summer heatwave growth accounting (inland regions)



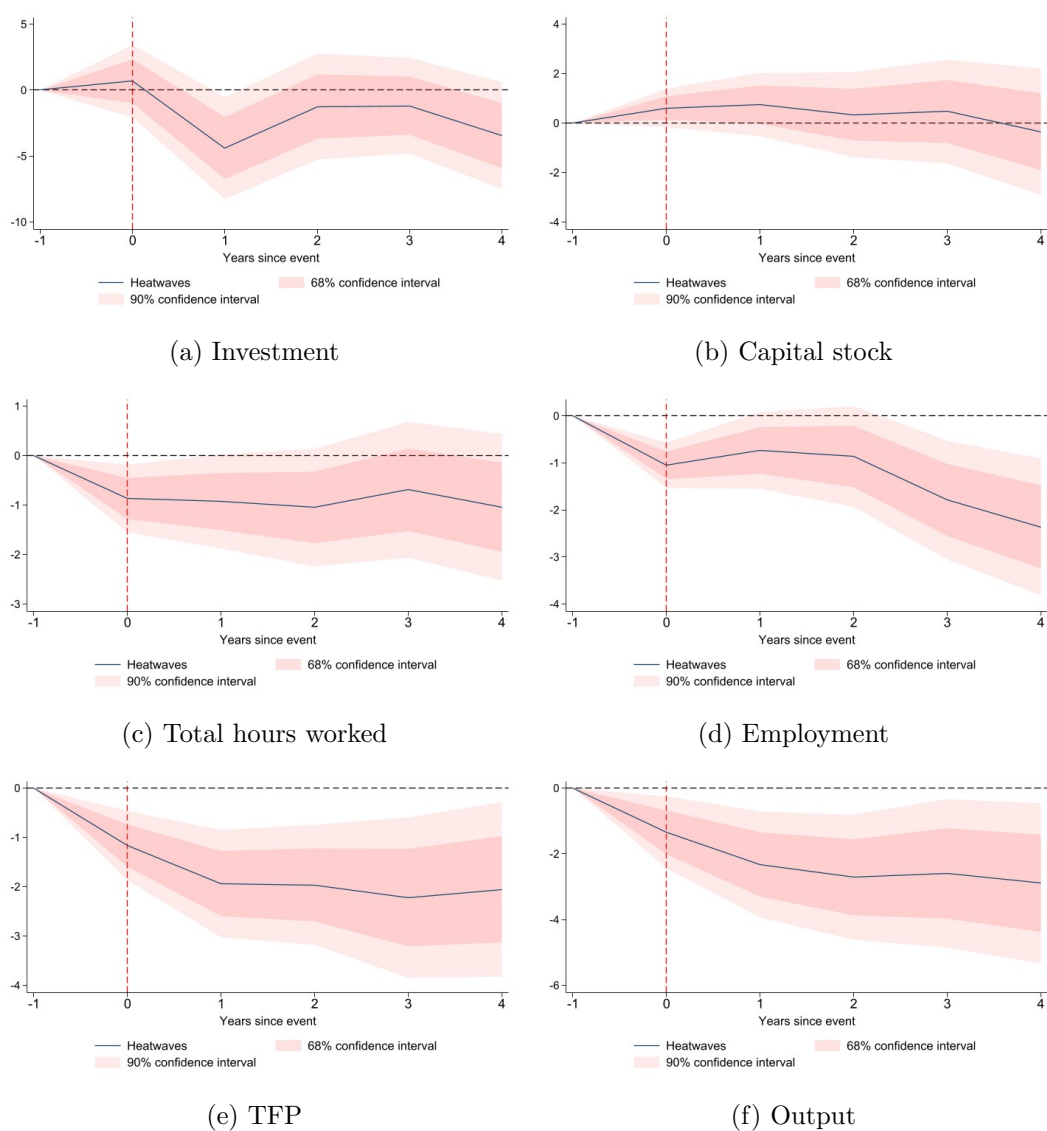
Note: Figure A7 shows medium-term effects of summer heatwaves on components of regional potential output of inland regions. Heatwaves are defined as deviations of seasonal temperature from historical mean (1991-2020) above 1.5 degree Celsius threshold. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A8) Summer heatwave growth accounting (rural regions)



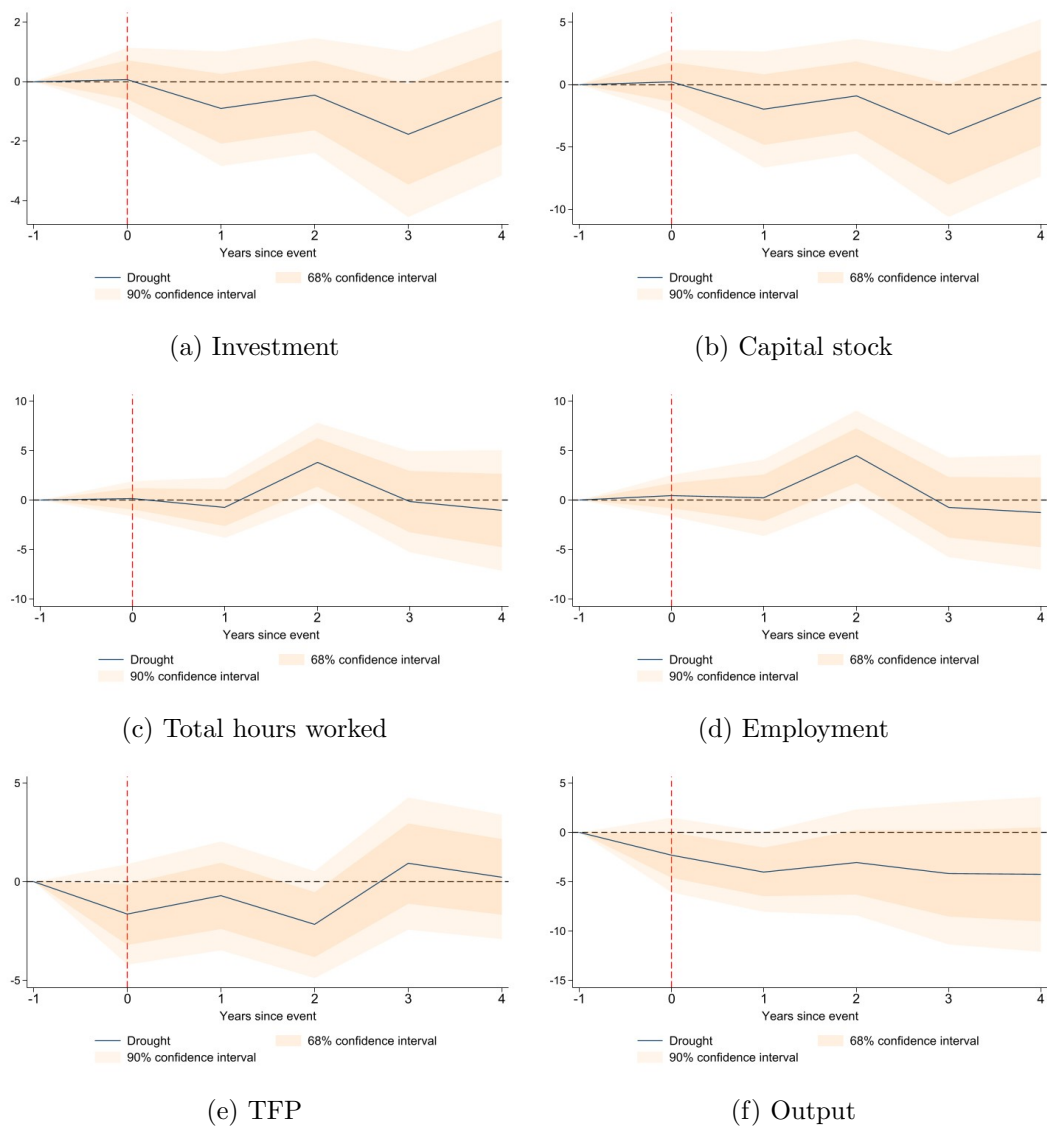
Note: Figure A8 shows medium-term effects of summer heatwaves on components of regional potential output of rural regions. Heatwaves are defined as deviations of seasonal temperature from historical mean (1991-2020) above 1.5 degree Celsius threshold. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A9) Summer heatwave growth accounting (urban regions)



Note: Figure A9 shows medium-term effects of summer heatwaves on components of regional potential output of urban regions. Heatwaves are defined as deviations of seasonal temperature from historical mean (1991-2020) above 1.5 degree Celsius threshold. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

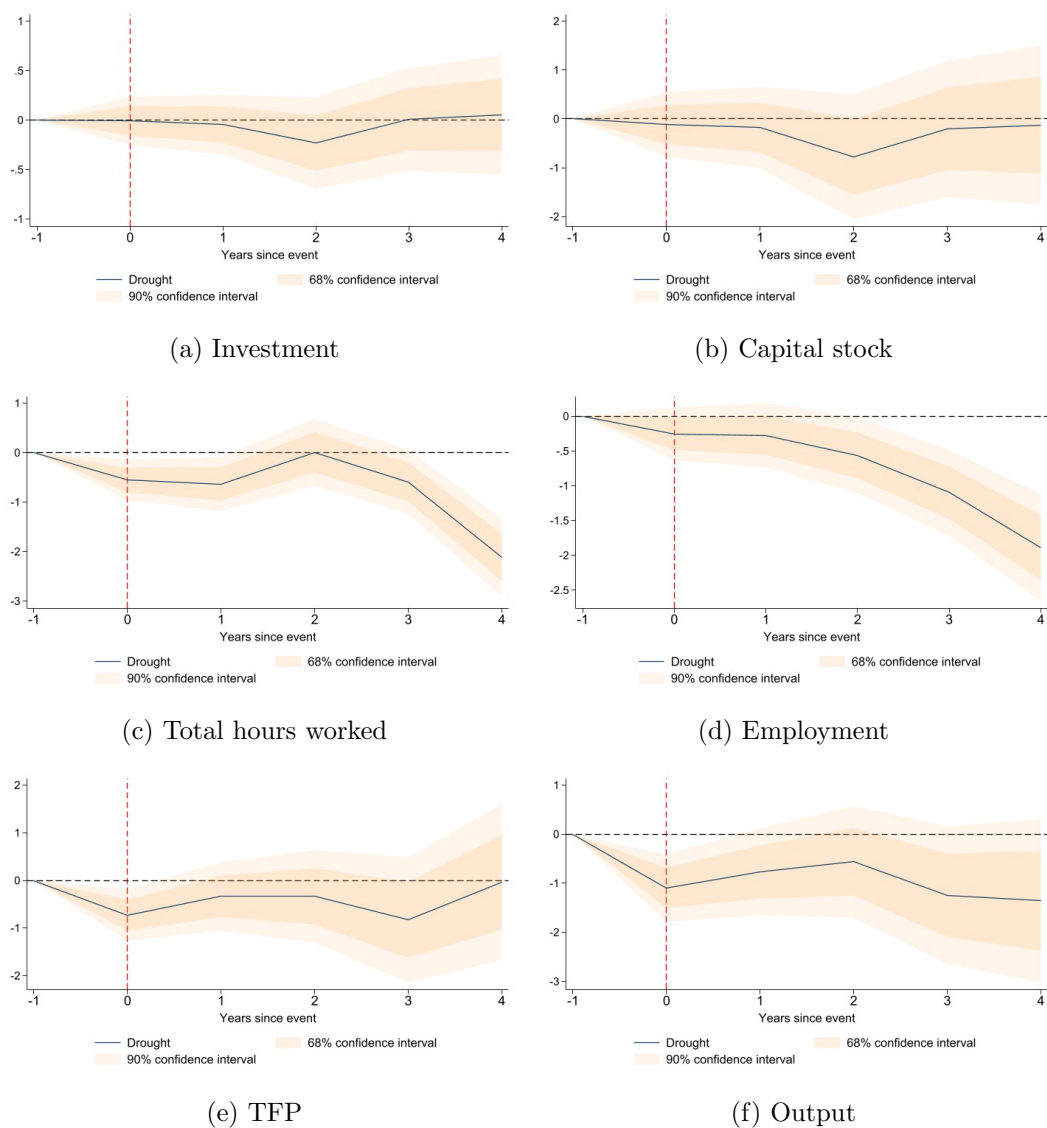
Figure (A10) Droughts growth accounting (hot regions)



Note: Figures A10 shows medium-term effects of droughts on regional components of potential output of hot regions. The event of drought is a binary variable that takes the value 1 if a regions for three consecutive months has total monthly precipitation less than 50 percent of historical mean of monthly precipitation (1991-2020). X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

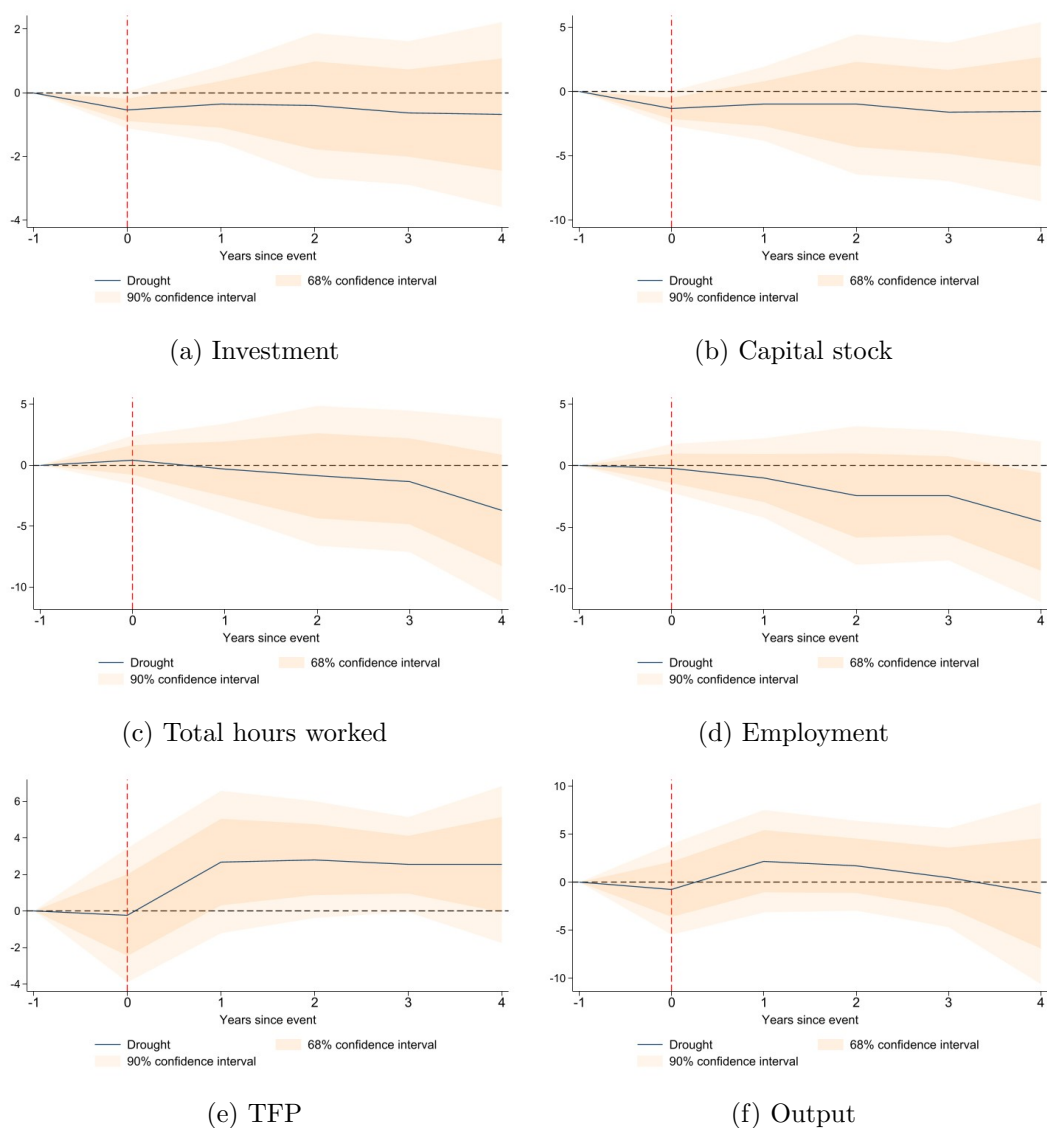


Figure (A11) Droughts growth accounting (temperate regions)



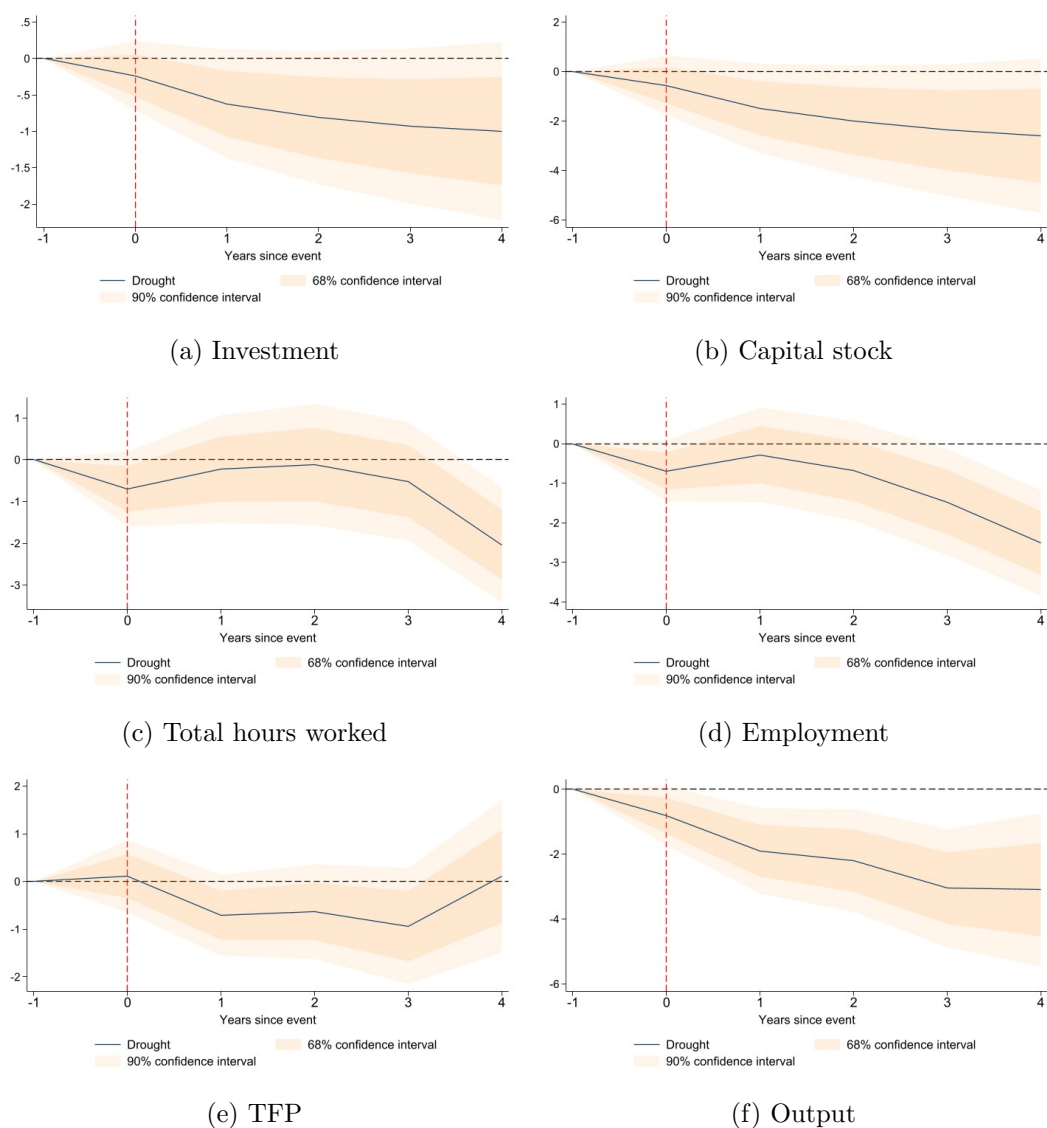
Note: Figures A11 shows medium-term effects of droughts on regional components of potential output of temperate regions. The event of drought is a binary variable that takes the value 1 if a region for three consecutive months has total monthly precipitation less than 50 percent of the historical mean of monthly precipitation (1991-2020). X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A12) Droughts growth accounting (cold regions)



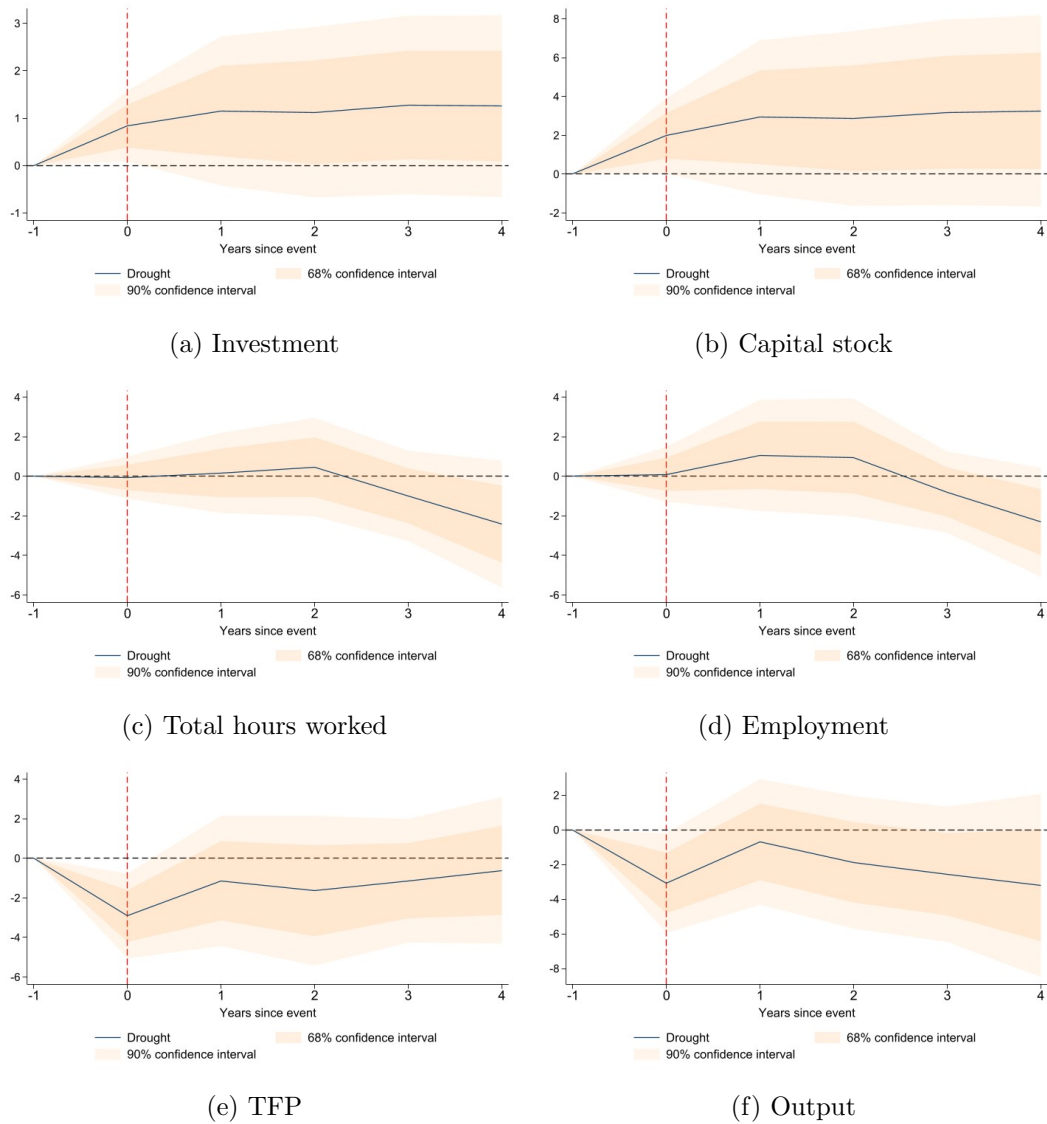
Note: Figures A10 shows medium-term effects of droughts on regional components of potential output of cold regions. The event of drought is a binary variable that takes the value 1 if a regions for three consecutive months has total monthly precipitation less than 50 percent of historical mean of monthly precipitation (1991-2020). X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A13) Droughts growth accounting (urban regions)



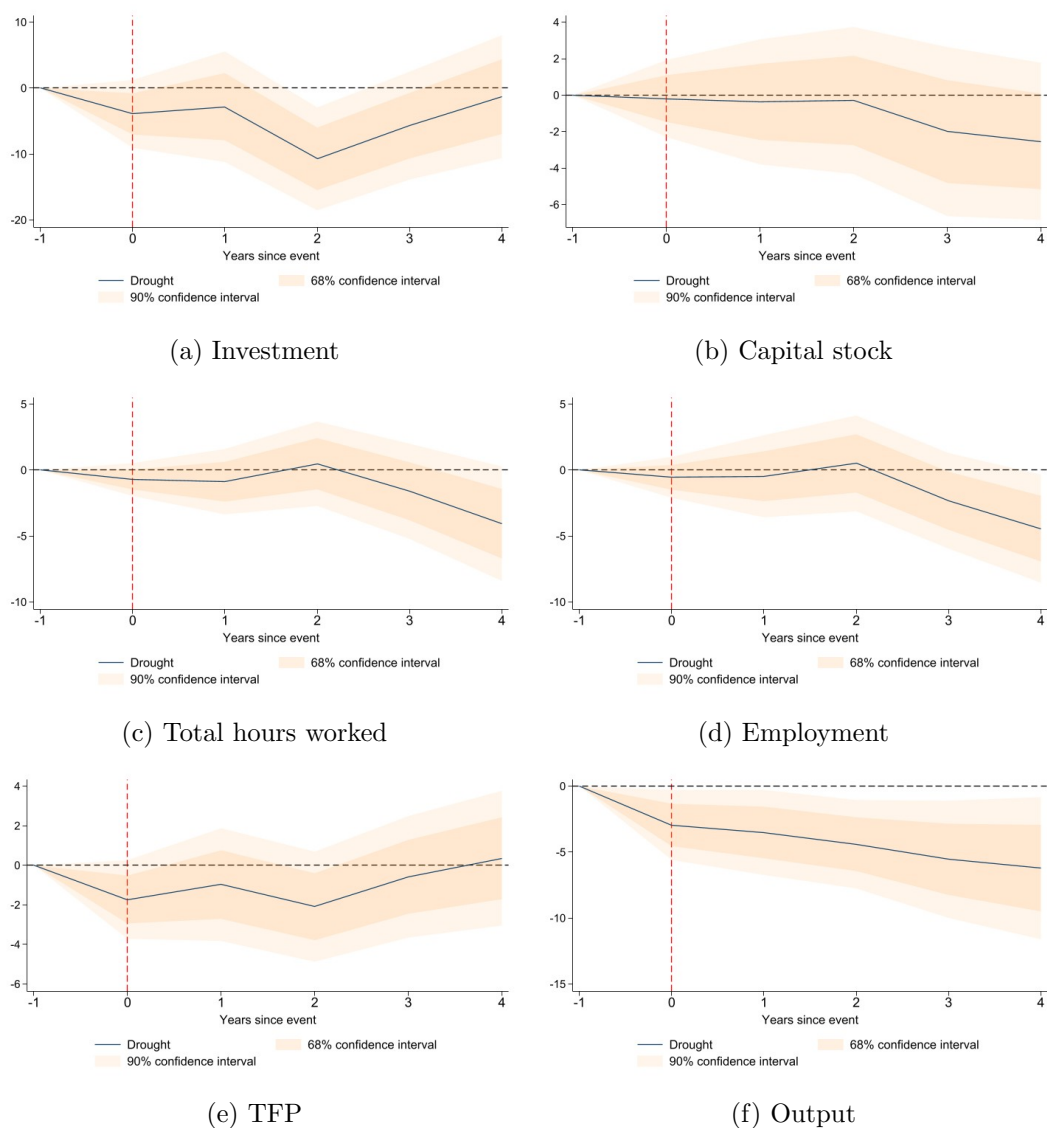
Note: Figures A13 shows medium-term effects of droughts on regional components of potential output of urban regions. The event of drought is a binary variable that takes the value 1 if a regions for three consecutive months has total monthly precipitation less than 50 percent of historical mean of monthly precipitation (1991-2020). X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A14) Droughts growth accounting (rural regions)



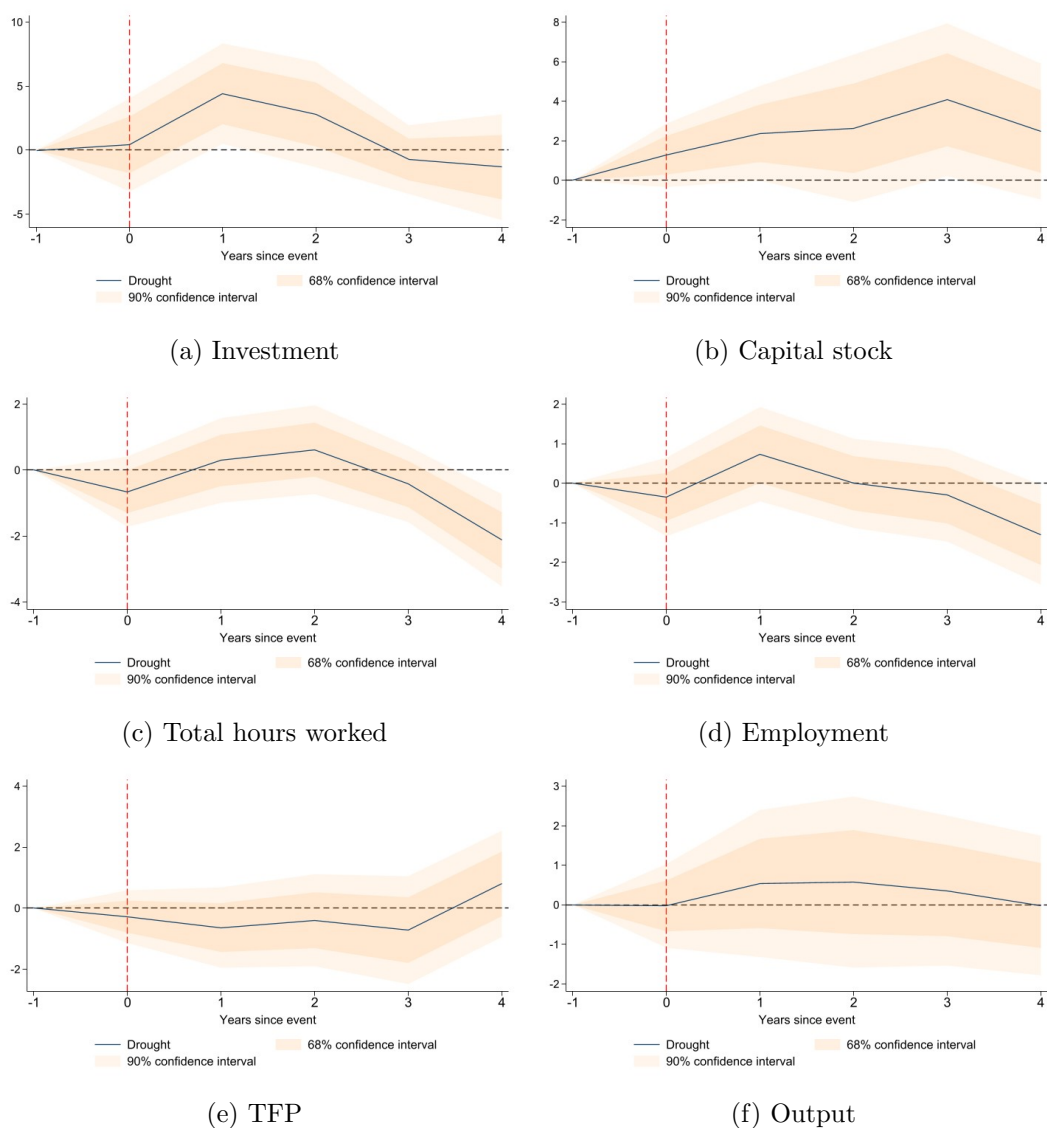
Note: Figures A14 shows medium-term effects of droughts on regional components of potential output of rural regions. The event of drought is a binary variable that takes the value 1 if a regions for three consecutive months has total monthly precipitation less than 50 percent of historical mean of monthly precipitation (1991-2020). X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A15) Droughts growth accounting (low-income regions)



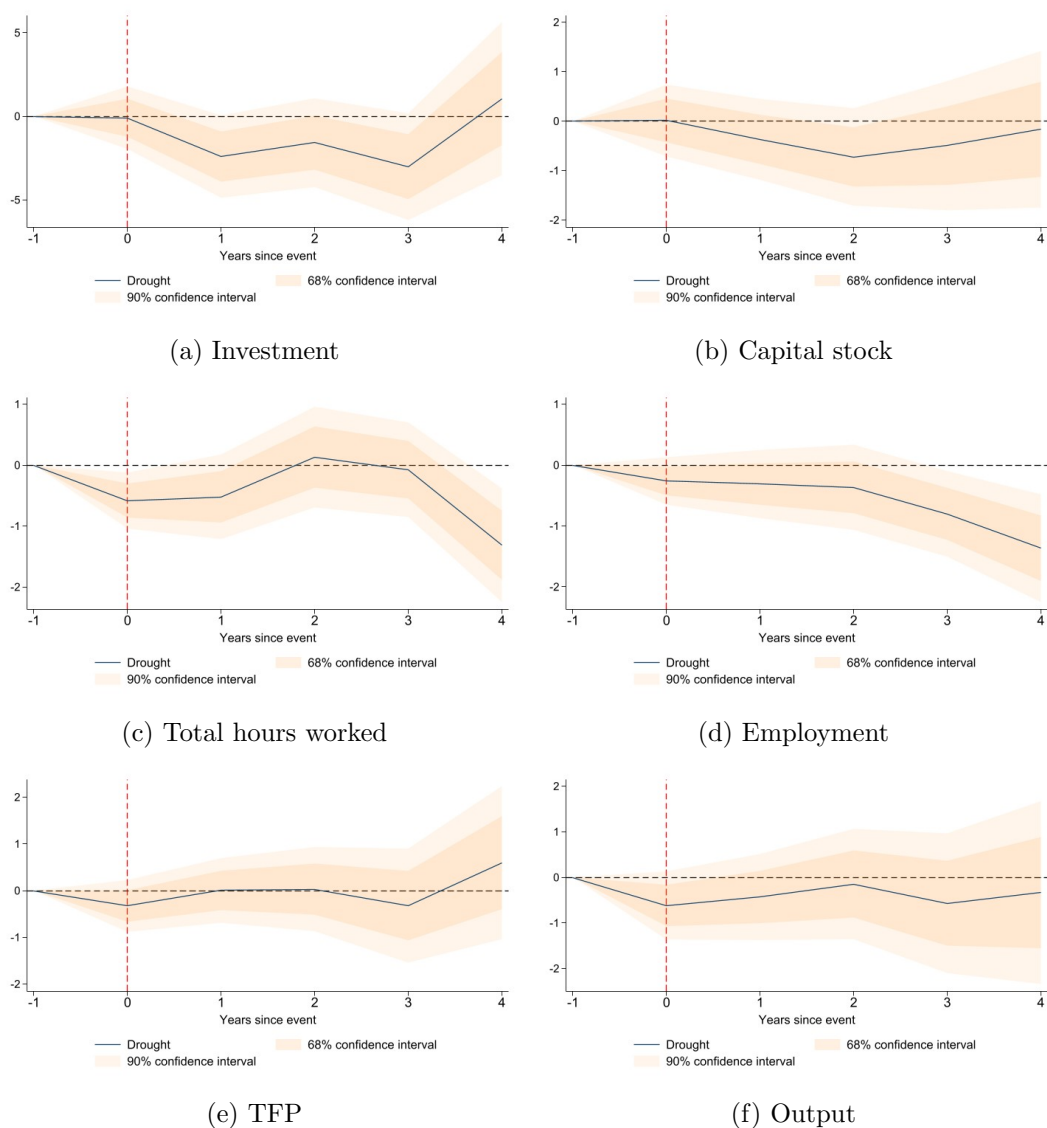
Note: Figures A15 shows medium-term effects of droughts on regional components of potential output of low-income regions. The event of drought is a binary variable that takes the value 1 if a regions for three consecutive months has total monthly precipitation less than 50 percent of historical mean of monthly precipitation (1991-2020). X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A16) Droughts growth accounting (middle-income regions)



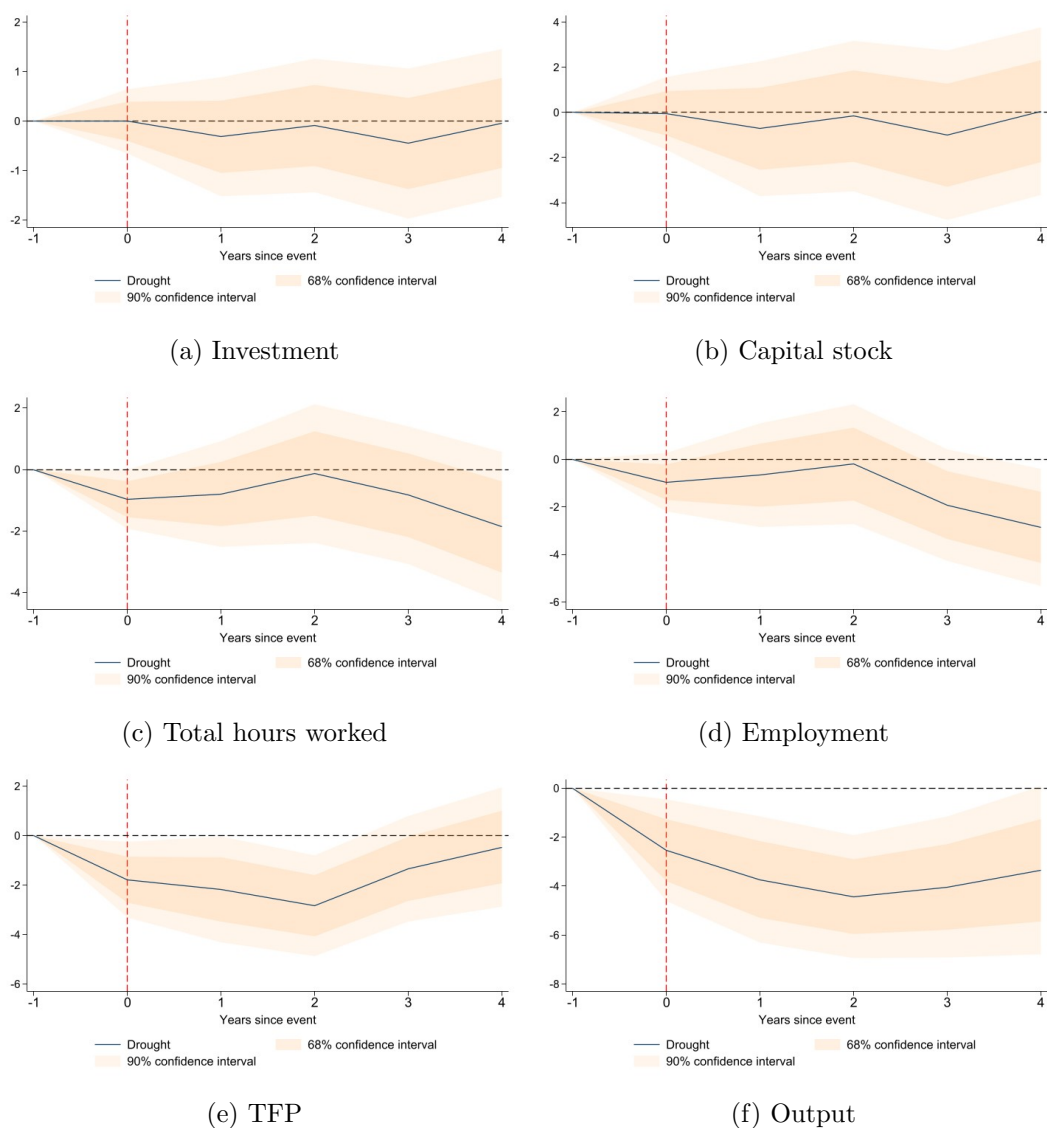
Note: Figures A16 shows medium-term effects of droughts on regional components of potential output of low-income regions. The event of drought is a binary variable that takes the value 1 if a regions for three consecutive months has total monthly precipitation less than 50 percent of historical mean of monthly precipitation (1991-2020). X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A17) Droughts growth accounting (high-income regions)



Note: Figures A17 shows medium-term effects of droughts on regional components of potential output of high-income regions. The event of drought is a binary variable that takes the value 1 if a regions for three consecutive months has total monthly precipitation less than 50 percent of historical mean of monthly precipitation (1991-2020). X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

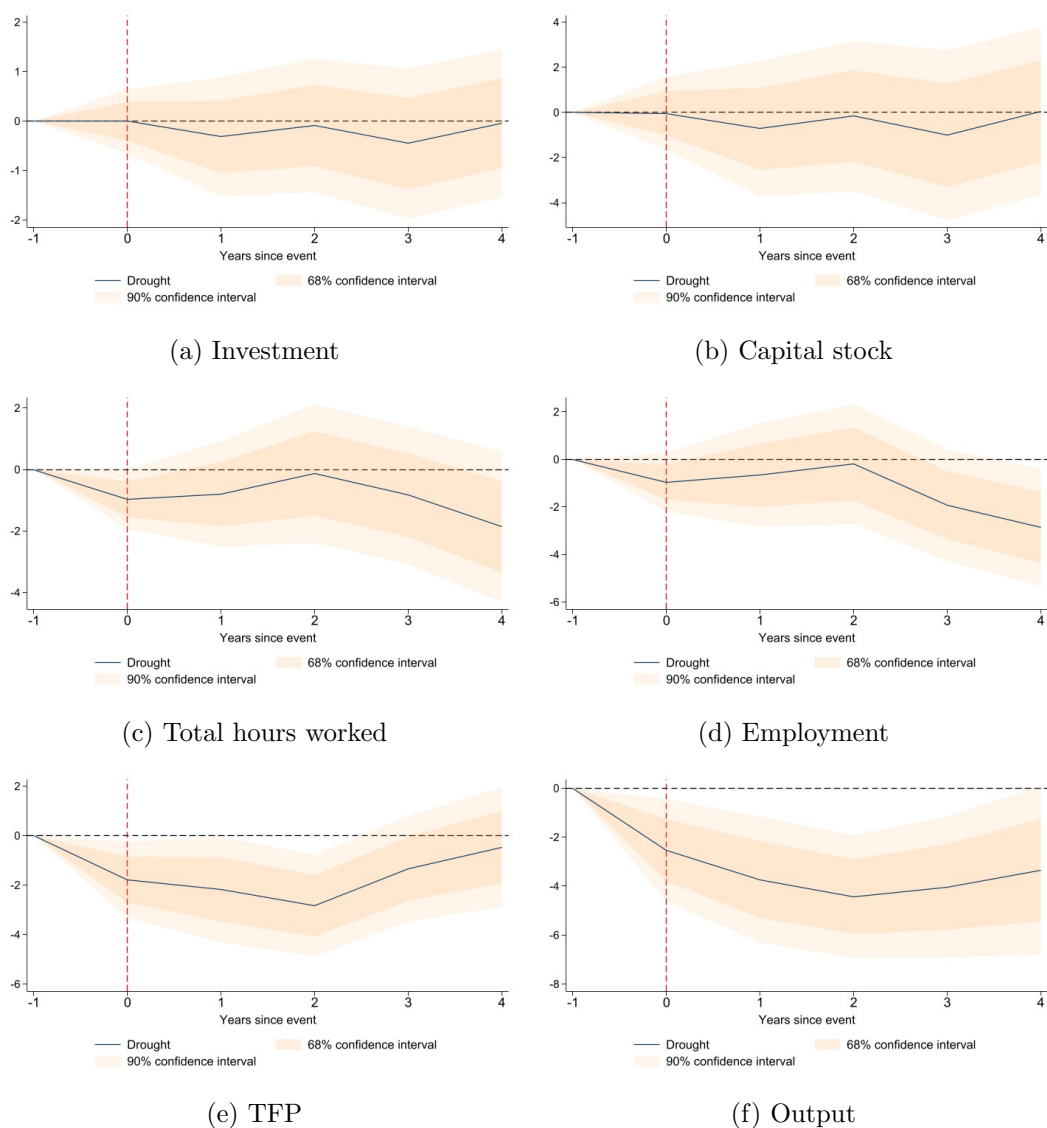
Figure (A18) Droughts growth accounting (coastal regions)



Note: Figures A18 shows medium-term effects of droughts on regional components of potential output of coastal regions. The event of drought is a binary variable that takes the value 1 if a regions for three consecutive months has total monthly precipitation less than 50 percent of historical mean of monthly precipitation (1991-2020). X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

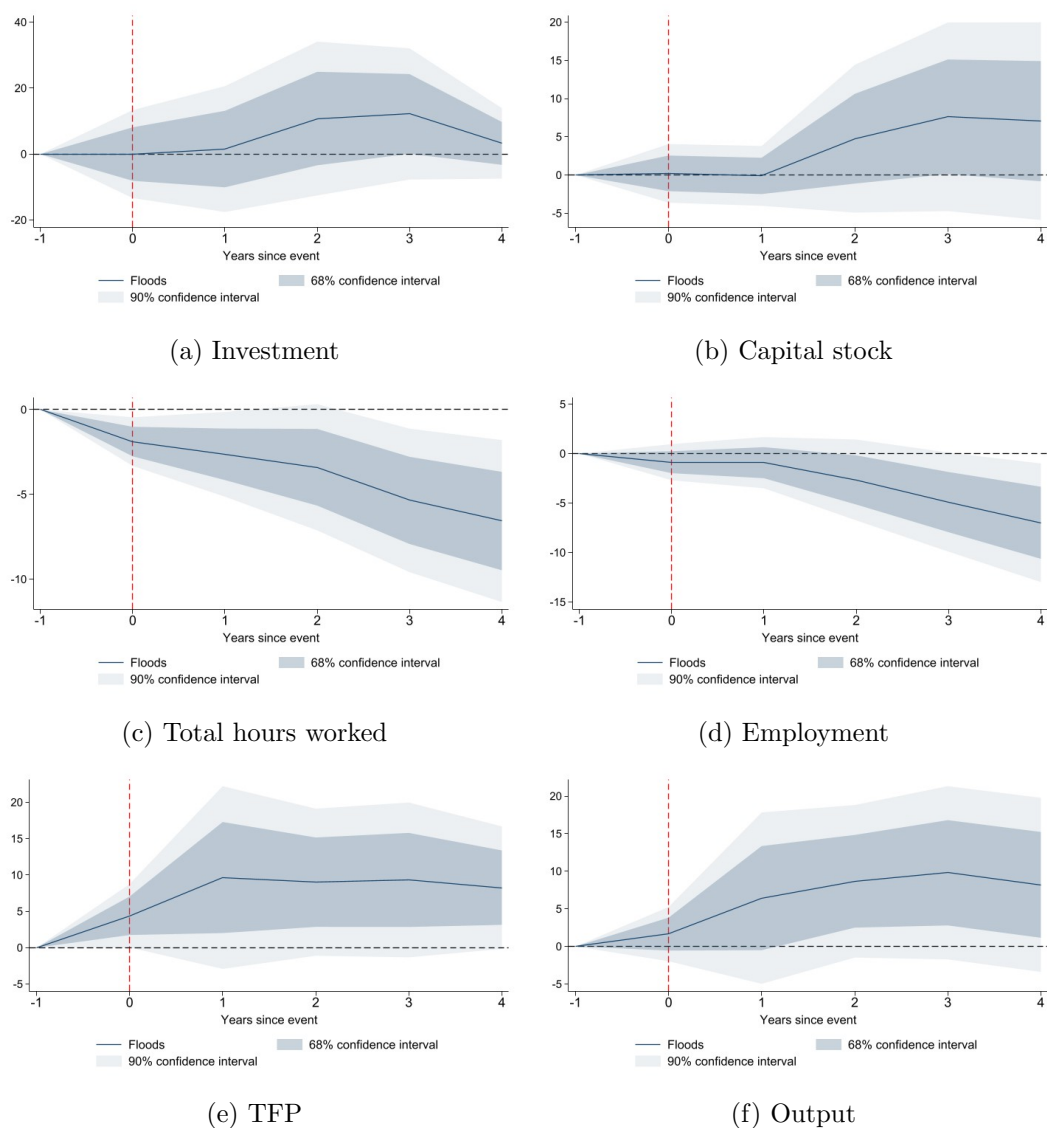


Figure (A19) Droughts growth accounting (inland regions)



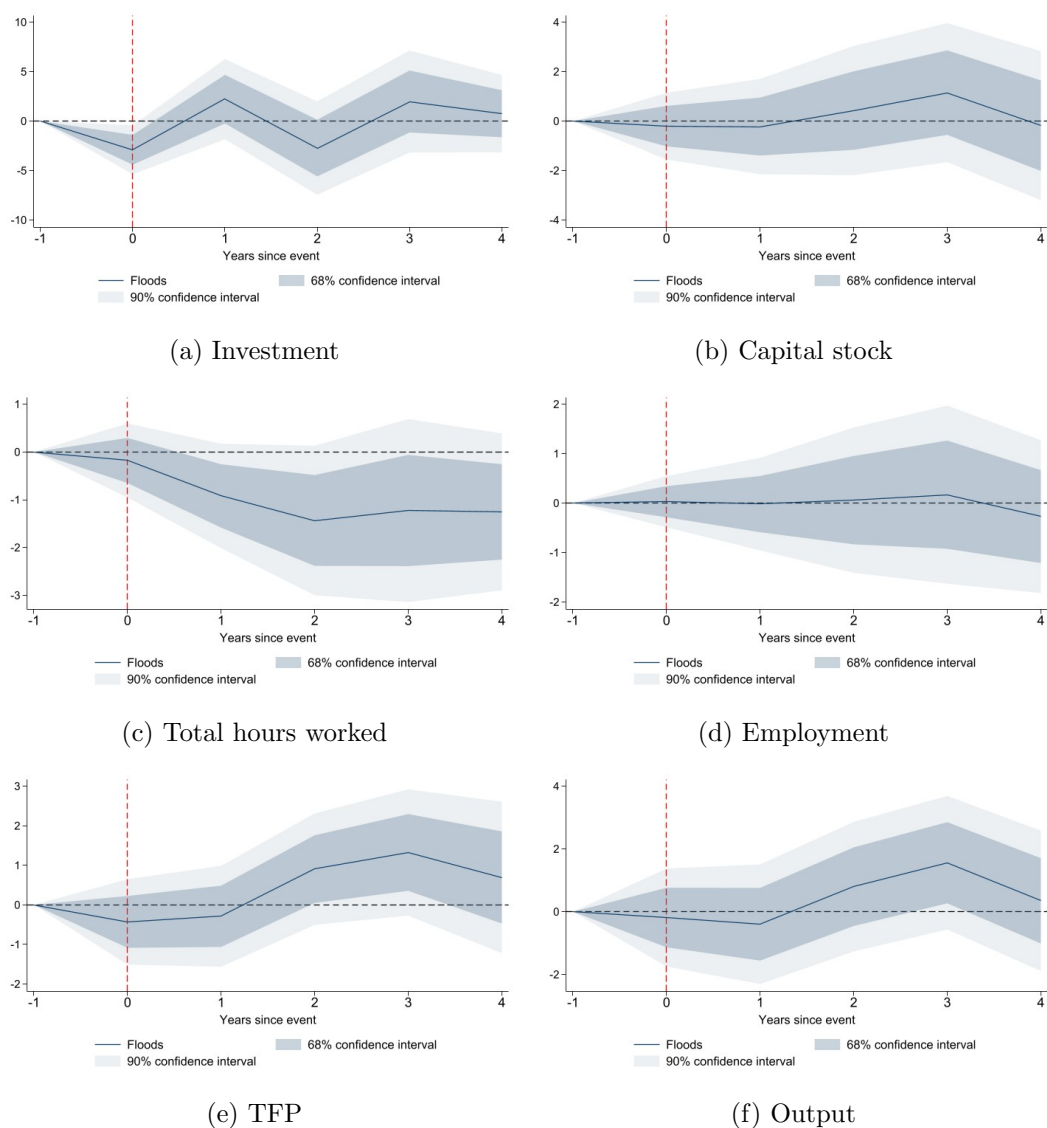
Note: Figures A19 shows medium-term effects of droughts on regional components of potential output of inland regions. The event of drought is a binary variable that takes the value 1 if a regions for three consecutive months has total monthly precipitation less than 50 percent of historical mean of monthly precipitation (1991-2020). X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A20) Floods growth accounting (hot regions)



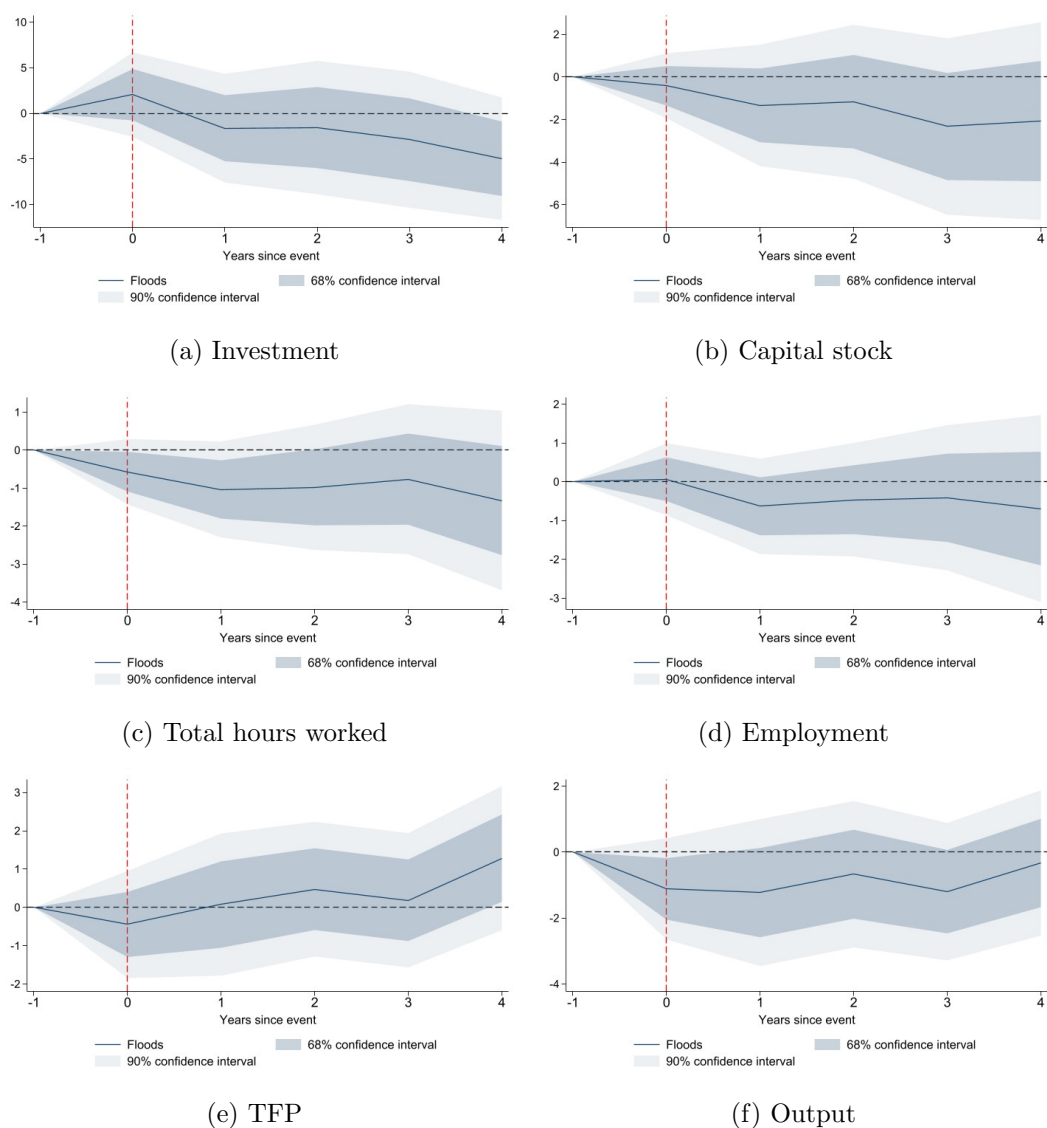
Note: Figure A20 shows medium-term effects of floods on components of regional potential output of hot regions. The event of flood is a binary variable that takes the value 1 if standardised precipitation index for at least once in a month shows extremely wet conditions. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A21) Floods growth accounting (temperate regions)



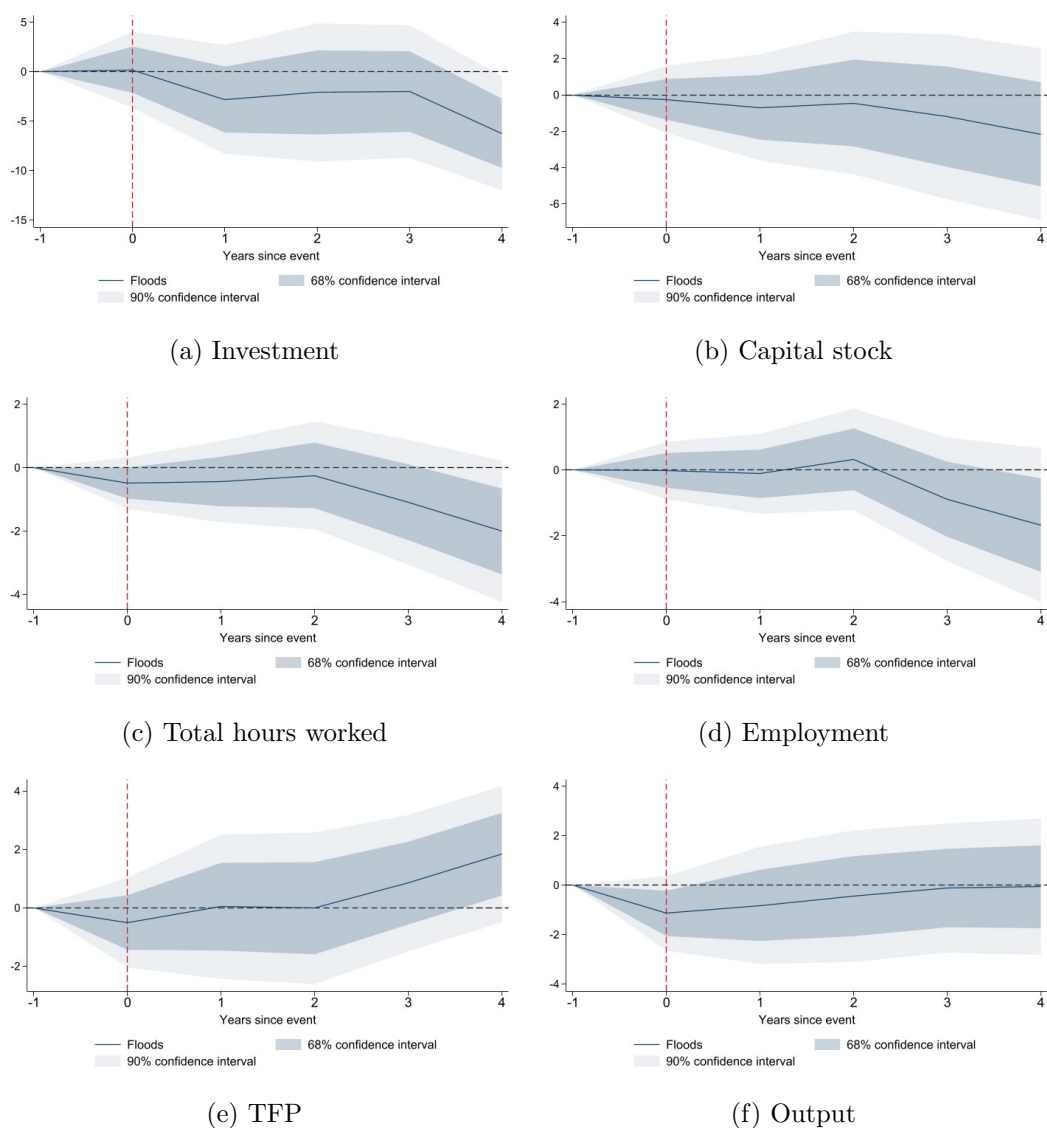
Note: Figure A21 shows medium-term effects of floods on components of regional potential output of temperate regions. The event of flood is a binary variable that takes the value 1 if standardised precipitation index for at least once in a month shows extremely wet conditions. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A22) Floods growth accounting (cold regions)



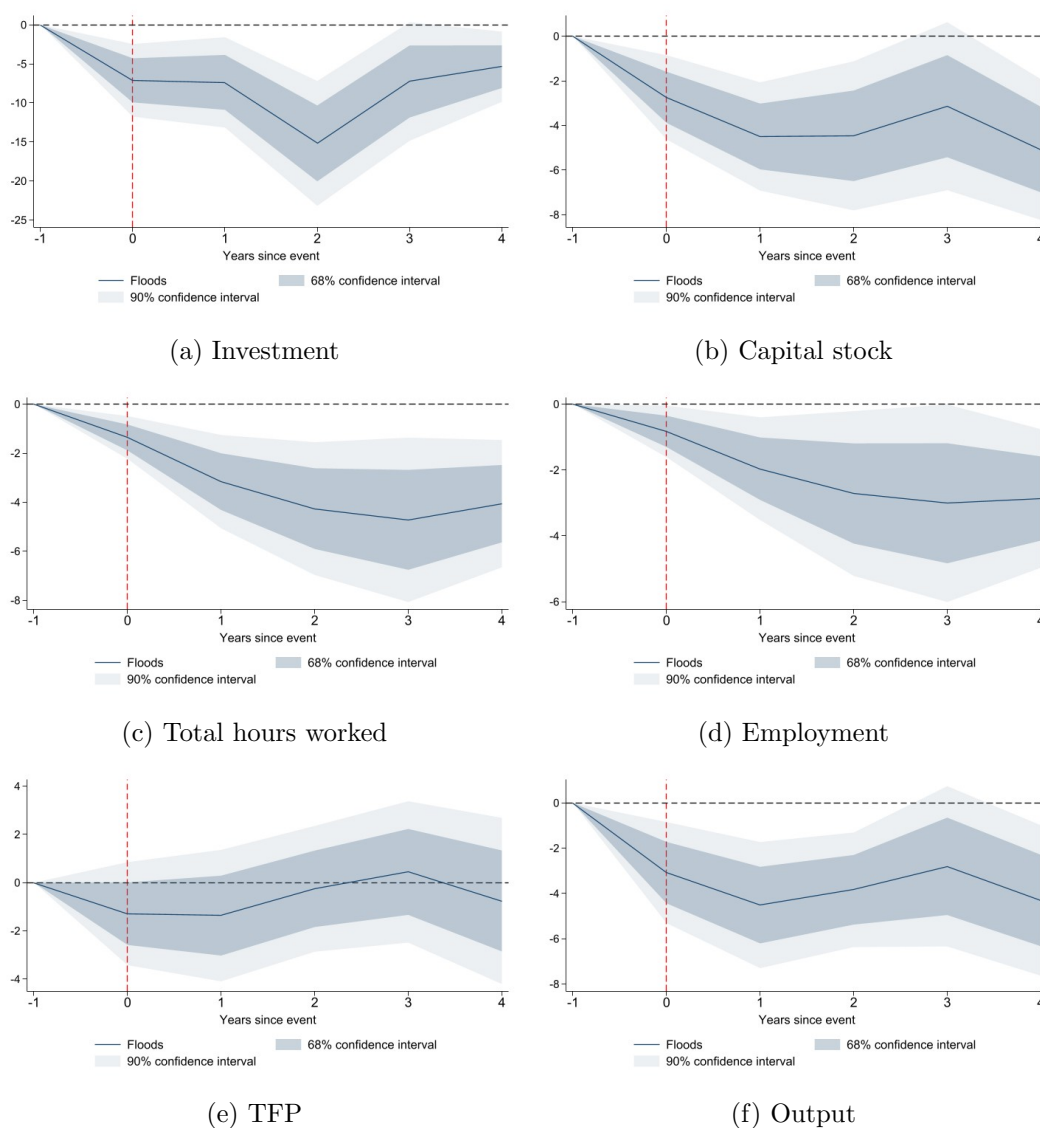
Note: Figure A22 shows medium-term effects of floods on components of regional potential output of cold regions. The event of flood is a binary variable that takes the value 1 if standardised precipitation index for at least once in a month shows extremely wet conditions. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A23) Floods growth accounting (low income regions)



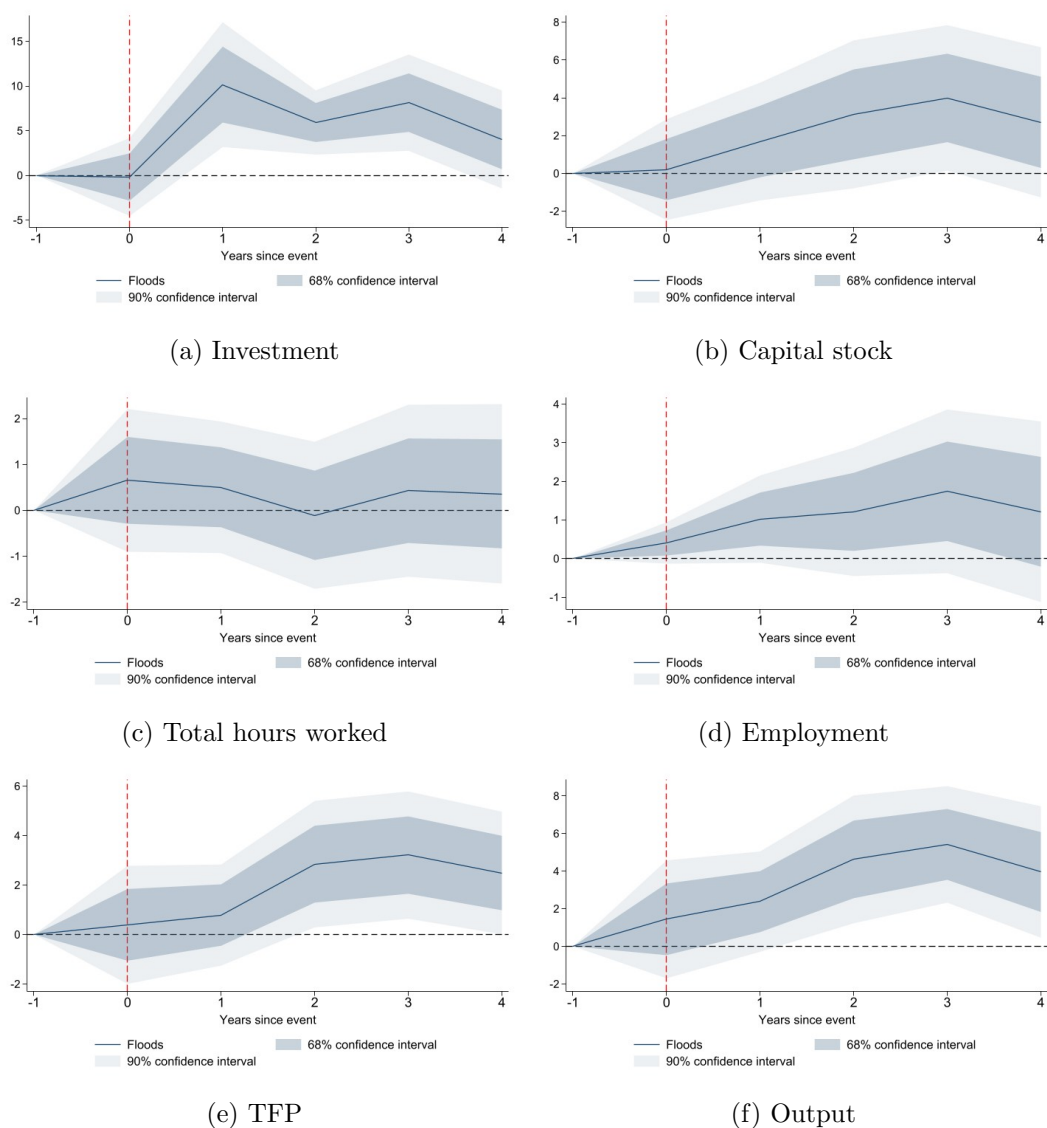
Note: Figure A23 shows medium-term effects of floods on components of regional potential output of low-income regions. The event of flood is a binary variable that takes the value 1 if standardised precipitation index for at least once in a month shows extremely wet conditions. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A24) Floods growth accounting (middle-income regions)



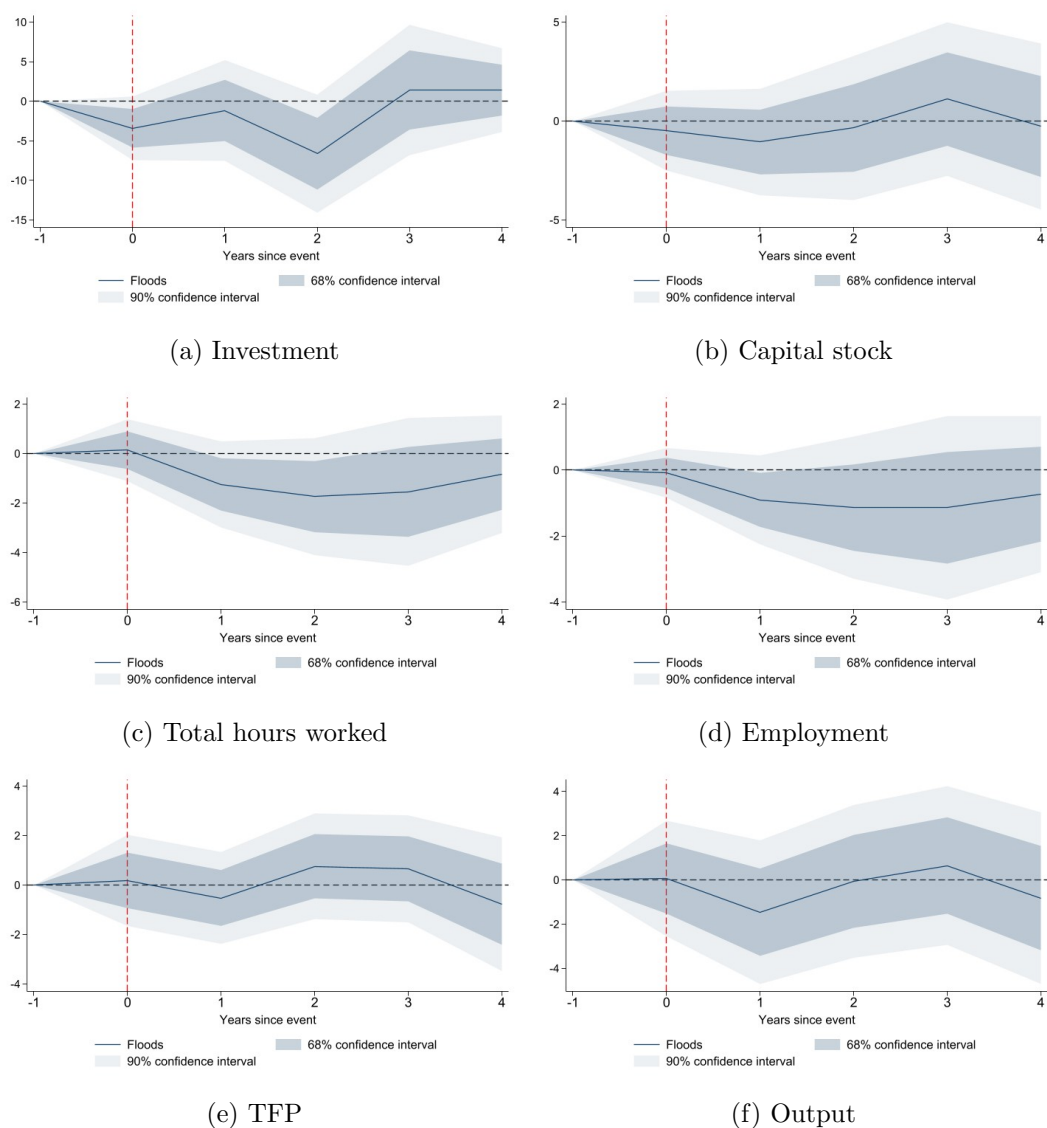
Note: Figure A25 shows medium-term effects of floods on components of regional potential output of middle-income regions. The event of flood is a binary variable that takes the value 1 if standardised precipitation index for at least once in a month shows extremely wet conditions. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A25) Floods growth accounting (high-income regions)



Note: Figure A25 shows medium-term effects of floods on components of regional potential output of high-income regions. The event of flood is a binary variable that takes the value 1 if standardised precipitation index for at least once in a month shows extremely wet conditions. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

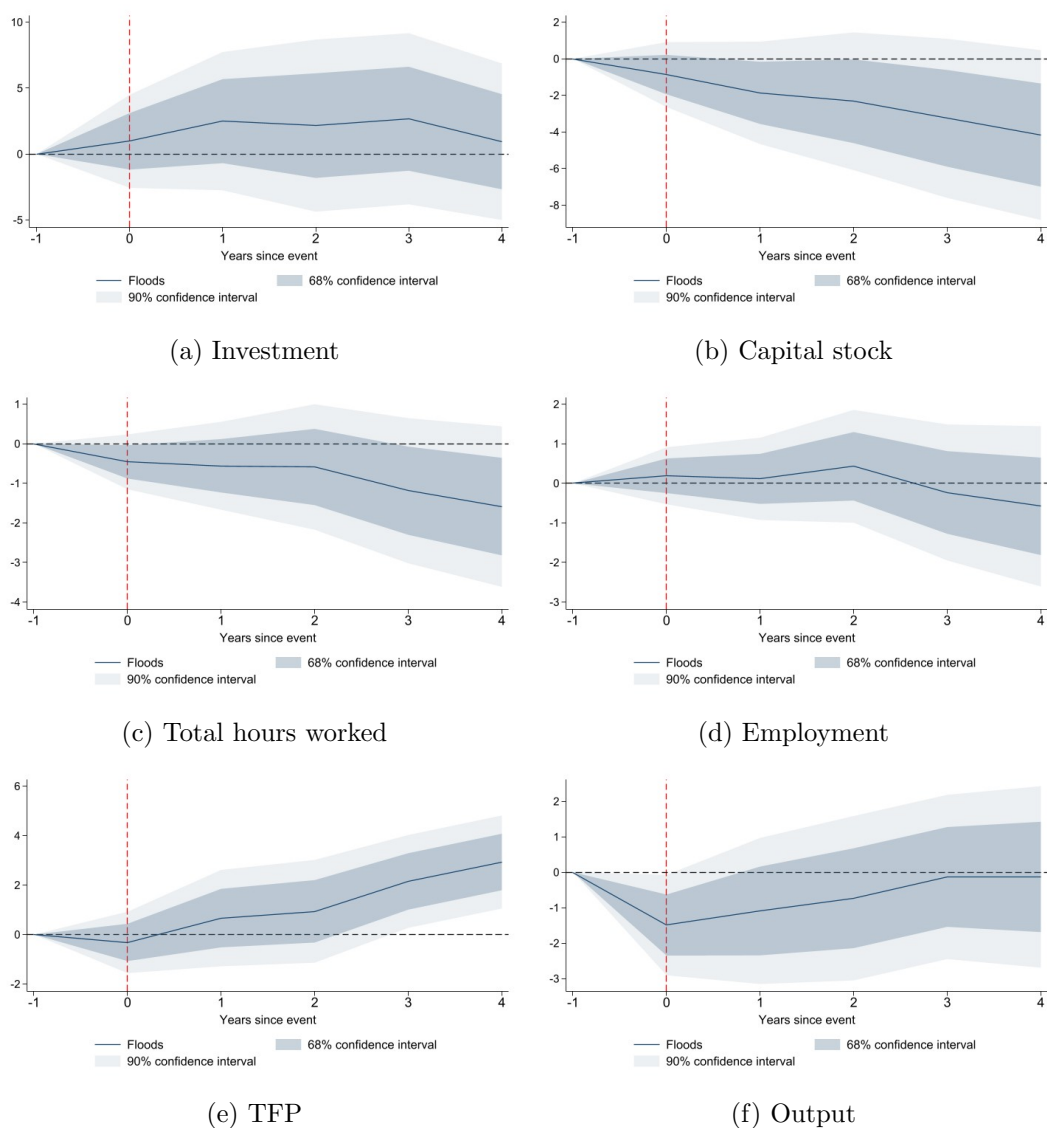
Figure (A26) Floods growth accounting (coastal regions)



Note: Figure A26 shows medium-term effects of floods on components of regional potential output of coastal regions. The event of flood is a binary variable that takes the value 1 if standardised precipitation index for at least once in a month shows extremely wet conditions. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

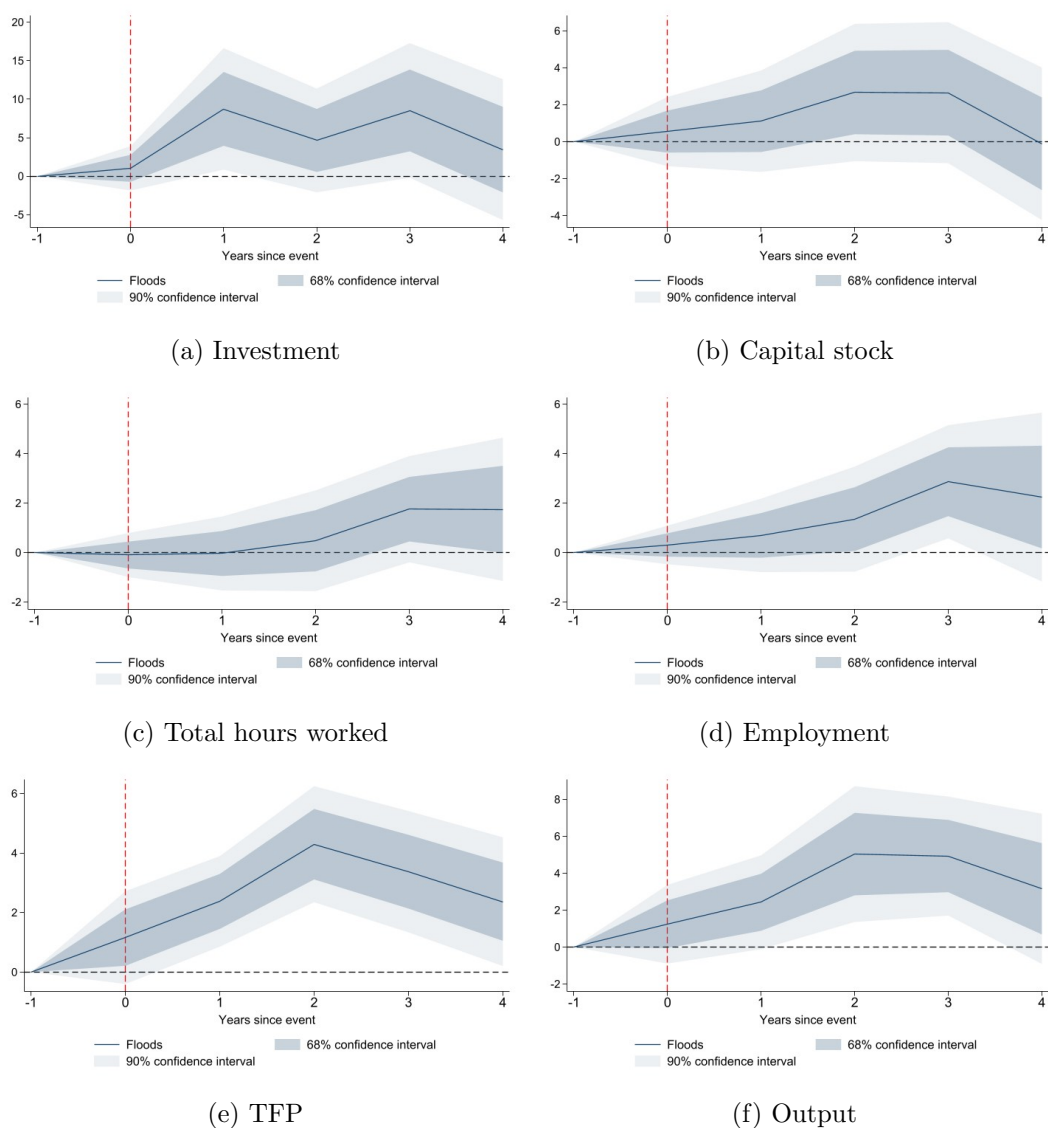


Figure (A27) Floods growth accounting (inland regions)



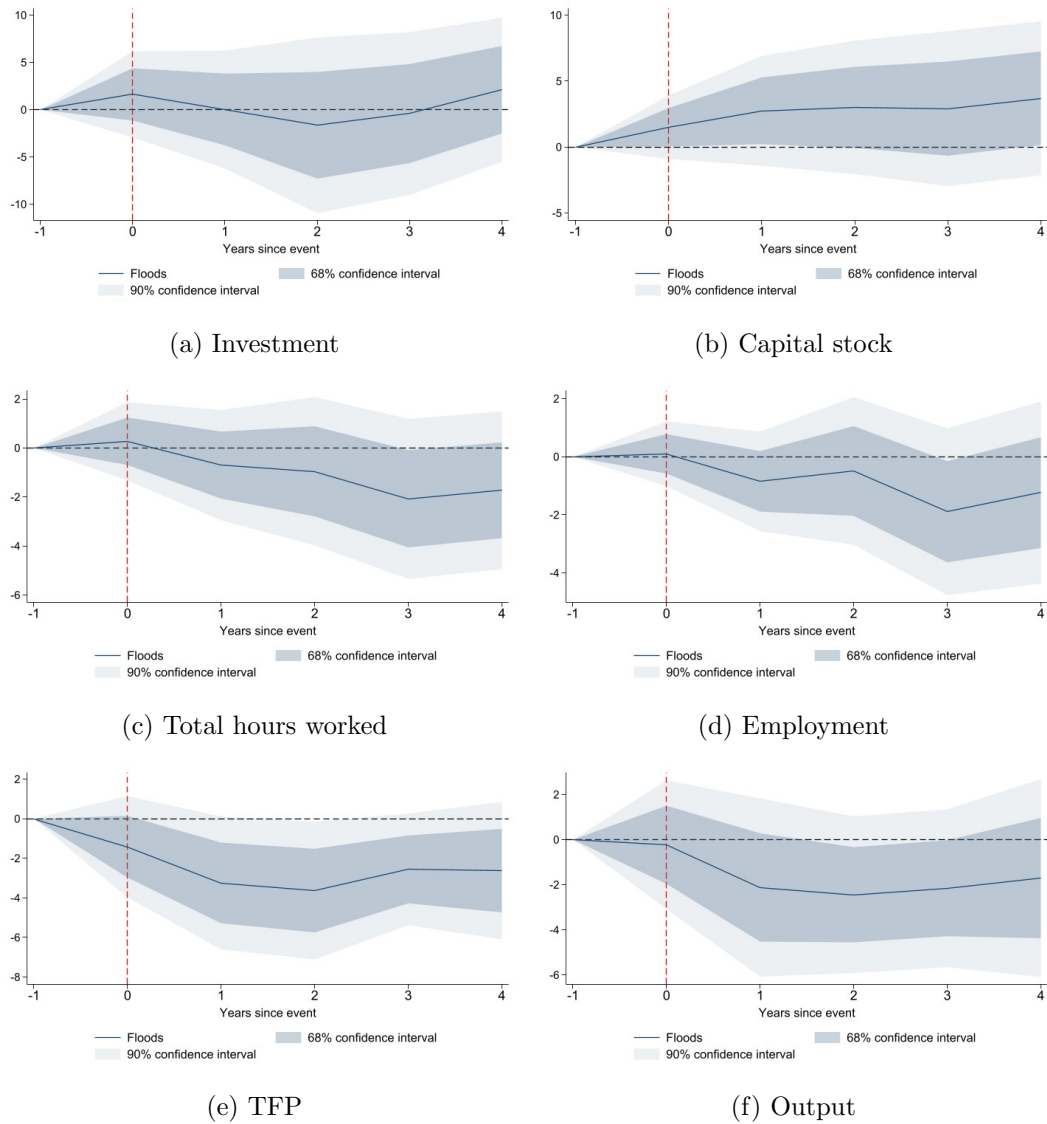
Note: Figure A27 shows medium-term effects of floods on components of regional potential output of inland regions. The event of flood is a binary variable that takes the value 1 if standardised precipitation index for at least once in a month shows extremely wet conditions. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A28) Floods growth accounting (urban regions)



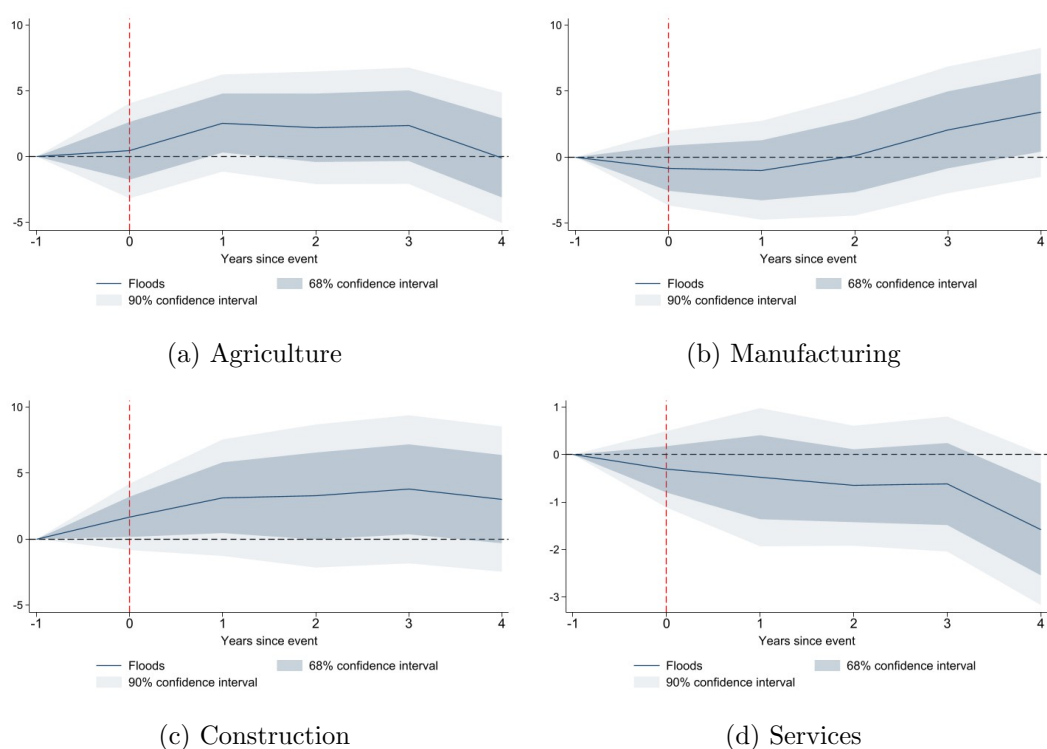
Note: Figure A28 shows medium-term effects of floods on components of regional potential output of urban regions. The event of flood is a binary variable that takes the value 1 if standardised precipitation index for at least once in a month shows extremely wet conditions. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A29) Floods growth accounting (rural regions)



Note: Figure A29 shows medium-term effects of floods on components of regional potential output of rural regions. The event of flood is a binary variable that takes the value 1 if standardised precipitation index for at least once in a month shows extremely wet conditions. X-axis shows the years after the shock in period 0 and y-axis shows percentage change in variable.

Figure (A30) Impact of floods on sectoral gross value added



Note: Figure A30 shows medium-term effects of floods on gross value added of NUTS-3 regions by sector. The event of a flood is a binary variable that takes the value one if the standardised precipitation index for at least once in a month shows extremely wet conditions. The X-axis shows the years after the shock in period 0, and the y-axis shows the percentage change in gross value added of the specific sector. For details on sector classification, see Table A1.

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