Weathering the Storm: Sectoral Economic and Inflationary Effects of Floods and the Role of Adaptation

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Introduction

Motivation

- Frequency and intensity of heavy precipitation have increased at the global level (IPCC, 2021)
  - Hydrological models project a larger fraction of land areas to be affected by an increase in floods

- In the UK flooding has intensified significantly over the last 50 years
  - Around 6 million UK properties at risk of flooding, a third of England has been flooded before (HM Government, 2022; Environment Agency, 2023)

- Floods are the most costly natural disaster
  - £1.4 billions are spent each year on damages from flooding (HM Government, 2023)
  - In 2021 expenditure on flood and coastal risk erosion management reached more than £1 billion

    ⇒ what is the role of adaptation policies? (Fried, 2022; Canova and Pappa, 2021)

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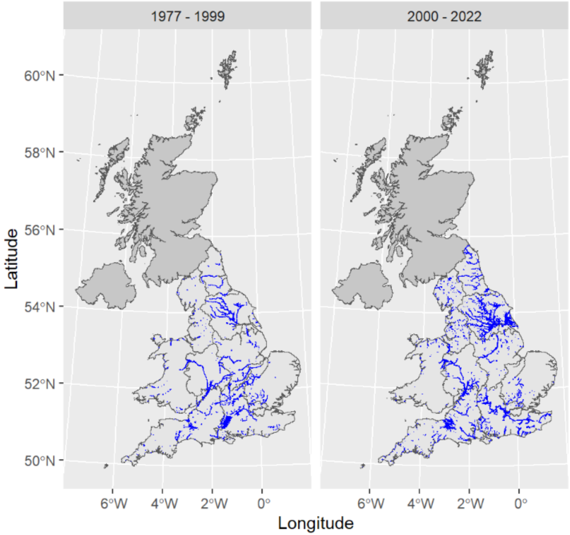
Flooding Has Intensified Significantly in the UK



Motivation

- Available evidence at very aggregate level (Kabundi et al., 2022; Cevik and Jalles, 2023) or for emerging economies (Panwar and Sen, 2020; Crofils et al., 2023), with poor identification of flood events (Parker, 2018; Heinen et al., 2019)
- Impact can vary by sector, *a priori* hard to determine response
  - Response of aggregate GDP and inflation is important, but often hard to make sense of (Cevik and Jalles, 2023; Bilal and Kanzig, 2024)
  - Sector-level analysis can reveal underlying dynamics
  - Supply or demand shock? Sectoral analysis can provide some answers (Acemoglu et al., 2016; Carvalho et al., 2021; Guerrieri et al., 2022; Ciccarelli and Marotta, 2024)

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Data

Data

- Yearly panel of **309 local authorities** (ITL3) for **1998-2021**
- Weather variables:
  - Recorded Flood Outlines database from UK Environment Agency
    Time Series | Map | Sources | Causes
  - Rainfall data from ERA5. Precipitation z-score for local authority i in year t:

$$P^z_{i,t} = \frac{P_{i,t} - \bar{P}_i}{\sigma^P_i} \qquad (1)$$

k-density

- Macroeconomic variables:
  - Aggregate and industry real output and prices + investments from ONS Industry breakdown
  - Real estate transactions from HM Land Registry + EPC database
  - Expenditure on defences against flooding from Ministry of Housing, Communities Local Government Time Series | Flood defences in England

Methodology

Empirical Strategy

- **Endogeneity concerns** related to adaptation capital
  - ↑ in adaptation capital might ↓ flood events and ↑ output (Fried, 2022)
  - Richer areas might have more policy space to build up adaptation capital that in turn ↓ flood events

- We adopt a local projection approach *à la* Jordà (2005) jointly with instrumental variable techniques (or **LP-IV**, see Jordà et al, 2015):

$$f_{i,t} = \alpha_i + \lambda_t + \delta P^z_{i,t} + \phi X_{i,t} + \Theta y_{i,t-1} + \xi_{i,t} \tag{2}$$

$$y_{i,t+h} = \alpha_i + \beta^h \hat{f}_{i,t} + \gamma X_{i,t} + \Theta y_{i,t-1} + \lambda_t + \varepsilon_{i,t+h}, \quad h = \{0;5\} \tag{3}$$

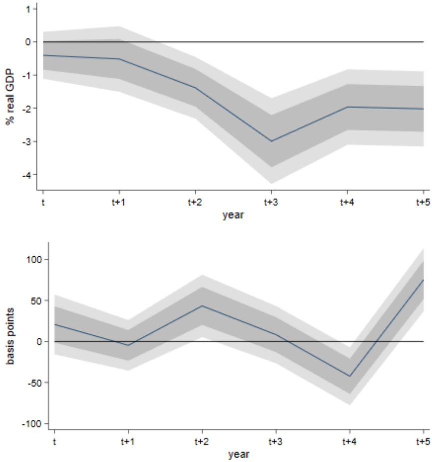
  - $y_{i,t+h}$ is in turn log (industry) GDP and (industry) inflation
  - $\hat{f}_{i,t}$: # of floods in local authority i in year t
  - β^h: cumulated response of GDP/prices to a flood shock in t
  - 1 lag of y, $X_{i,t}$ controls for population, ITL3 and year FE
  - standard errors clustered at local authority level

IV discussion

Results

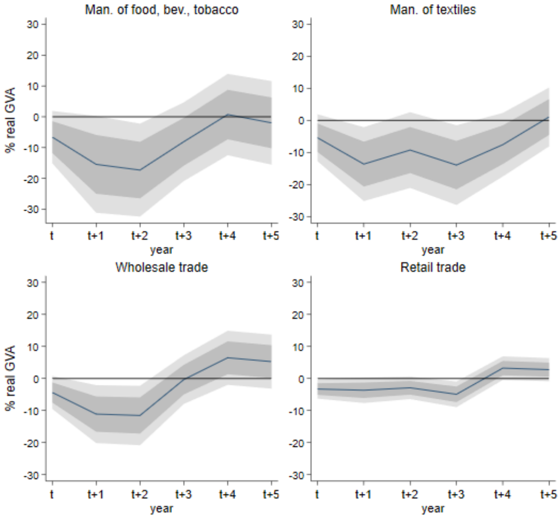
Aggregate Results

- Delayed and permanent decline in output, small temporary deviations in prices



Note: Response to a 1 st. dev. increase in the number of floods. Standard errors are clustered at the ITL3 level. Shaded areas denote 68% and 90% confidence bands.

Industry Analysis: Output I



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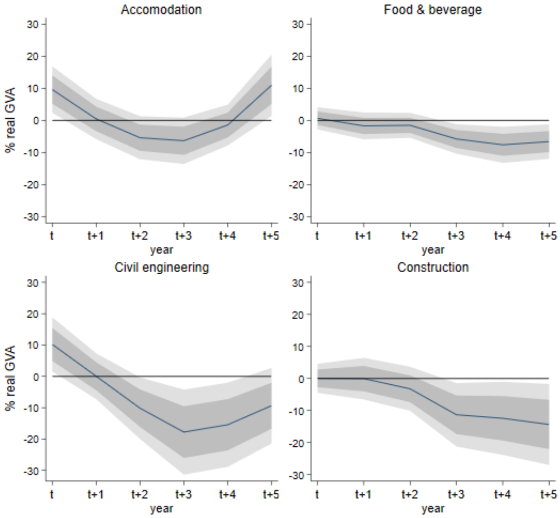
Industry Analysis: Output II



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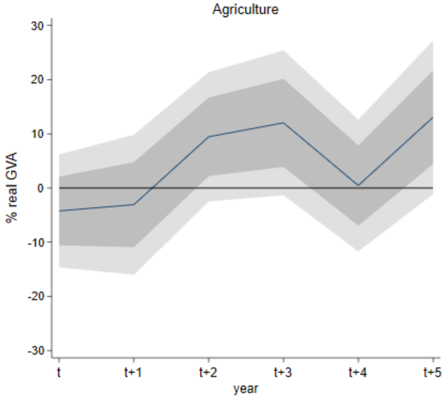
Industry Analysis: Output III



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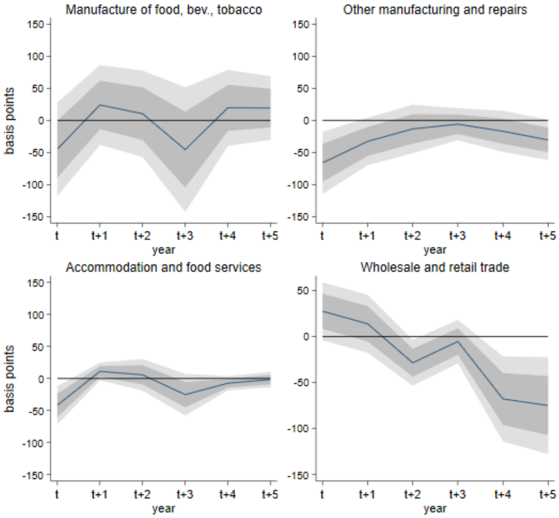
Industry Analysis: Prices I



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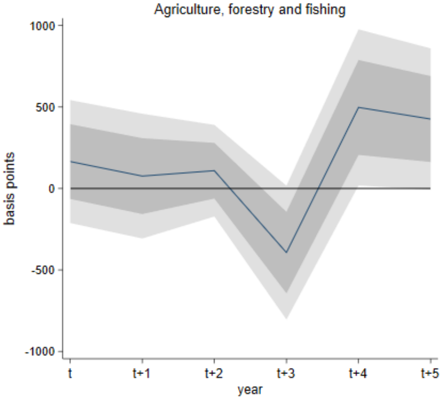
Industry Analysis: Prices II



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More on Industry Dynamics

- Investments have been shown to react to weather shocks (see e.g., Natoli, 2022) Aggregate IRFs Sector IRFs
  - Can't explain alone the decline in output, only manufacturing affected
- Wealth effect through real estate market transactions IRFs
  - Value of transactions initially increases due to a reduction in supply, then permanently dampens
  - Number of transactions declines
- Network effects exist Methodology IRFs
  - Shock **propagates** through the production network
  - Input-output linkages particularly strong in **manufacturing** and **trade**
  - Floods likely akin to both demand and supply shock, depending on sector

Investing in Adaptation

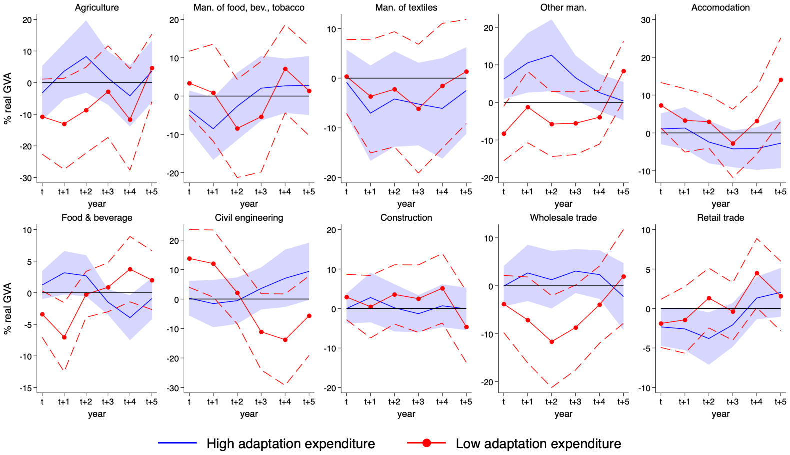
Adaptation Prevents Floods in Flood Prone Areas

Methodology

Dep: n. of floods	(1) t	(2) t+1	(3) t+2	(4) t+3	(5) t+4	(6) t+5
$exp_{i,t}$	-0.231	-0.791	-1.952	-3.879	-11.19**	-9.467
	(-0.14)	(-0.41)	(-0.79)	(-1.02)	(-2.50)	(-1.61)
$exp_{i,t} \times prone_i$	-8.187	-43.26	-74.51****	-1.762	-6.449	-12.14
	(-0.20)	(-1.30)	(-4.03)	(-0.04)	(-0.14)	(-0.39)
$k_{i,t}^{adapt.}$	-0.127	0.0195	-0.415	-0.877	0.0938	0.855
	(-0.26)	(0.04)	(-0.72)	(-1.15)	(0.09)	(0.93)
$k_{i,t}^{adapt.} \times prone_i$	-23.56*	-33.29**	-20.17***	-21.03**	-45.02**	-40.85***
	(-1.78)	(-2.48)	(-3.04)	(-2.31)	(-2.45)	(-2.94)
Obs.	4,326	4,326	4,017	3,708	3,399	3,090
ITL3 FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: Dependent variable is the number of floods. We include three lags of the dependent variable. Controls include population size and GDP. Standard errors clustered at the ITL3 level. t-statistics in parentheses.
* $p < 0.1$, **$p < 0.05$,*** $p < 0.01$, **** $p < 0.001$

Can Adaptation Reduce Damages? Methodology Prices Aggregate



Note: Response to a 1 st. dev. increase in the number of floods. Standard errors are clustered at the ITL3 level. Shaded areas denote 90% confidence bands.

Conclusions

Conclusions

- We study the impact of floods on GDP and prices in local authorities in England
- Aggregate results hide significant industry heterogeneities and underestimate the impact in some industries
  - Partially a wealth effect, impact propagates through the production network
  - Message for **policy**: don't stop at the aggregate!
  - Message for **CB**: not necessarily a monetary issue *right now*, can become in the *future*
- Government expenditure in adaptation capital reduces the likelihood of flooding in flood-prone areas, and can thus reduce the impact of floods on GDP and prices
  - Not as effective at the *intensive* margin
  - Message for **policy**: invest in adaptation!

For comments, questions, feedback:

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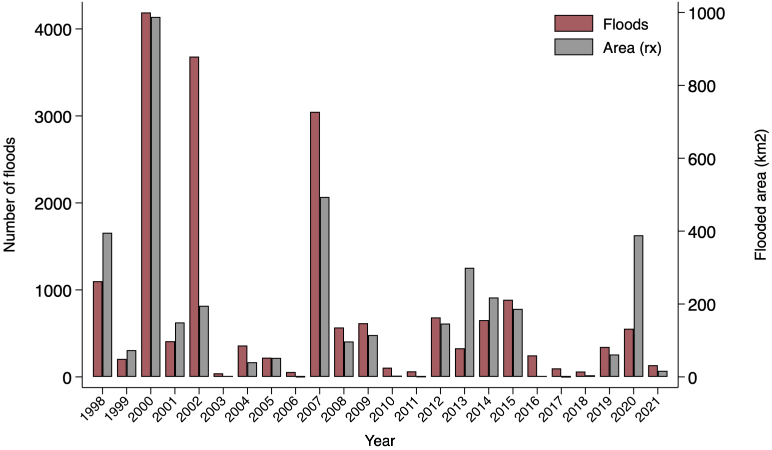
Annex

Annex I - 24 Years of Flood Events

Go back

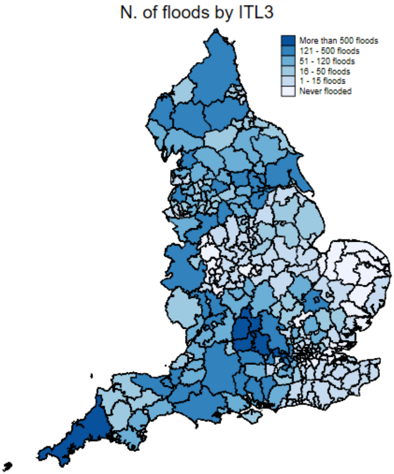
- Final sample: 18,735 flood events, average flood extends for 0.21km^2



Annex II - Flood Events by Local Authority

Go back

- Each local authority is flooded on average more than 2 times per year



Annex III - Sources of Flooding

Go back

Source of flooding	N. of Floods	% of total
Fluvial	13444	0.84
Coastal	300	0.02
Tidal	688	0.04
Other	1650	0.10

Source: Environment Agency's Recorded Flood Outlines

Annex IV - Causes of Flooding Go back

Cause of flooding	N. of Floods	% of total
Channel capacity exceeded (no raised defences)	9936	0.62
Groundwater/high water table	884	0.05
Local drainage/surface water	1123	0.07
Mechanical failure	3	0.00
Obstruction/blockage	284	0.02
Overtopping of defences	1154	0.07
Other	487	0.03
Unknown	2203	0.14

Source: Environment Agency's Recorded Flood Outlines

Annex V - *z*-score Density

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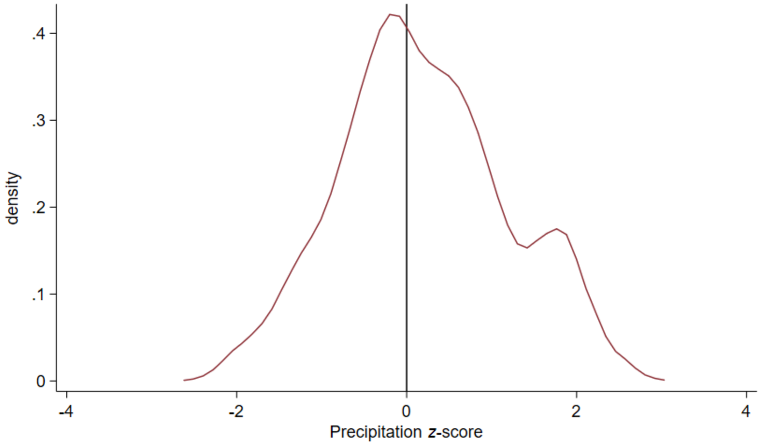


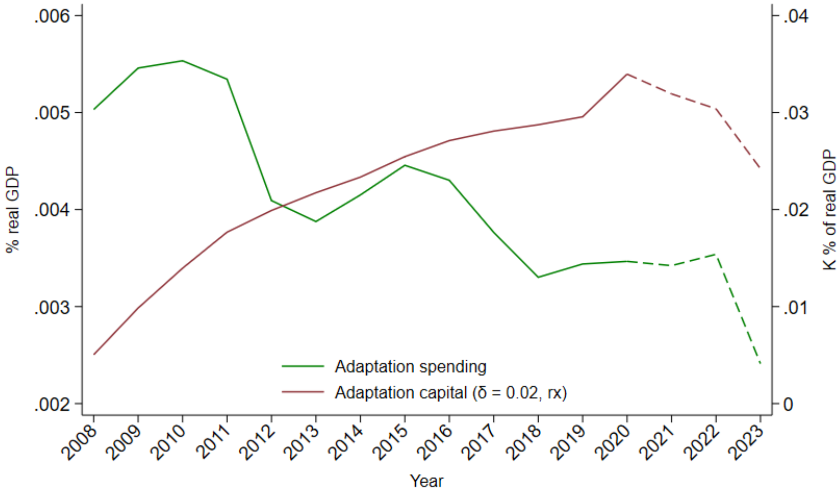
Annex VI - Breakdown of Industries Go back

Macro sector	Industry code	Industry name
Production	**AB (1-9)**	**Agriculture, forestry and fishing; mining and quarrying**
	C (10-33)	**Manufacturing**
	CA (10-12)	Manufacture of food, beverages and tobacco
	CB (13-15)	Manufacture of textiles, wearing apparel and leather
	CC (16-18)	Manufacture of wood and paper products and printing
	CD-CG (19-23)	Manufacture of petroleum, chemicals and other minerals
	CH (24-25)	Manufacture of basic and fabricated metal products
	CI-CJ (26-27)	Manufacture of electronic, optical and electrical products
	CK-CL (28-30)	Manufacture of machinery and transport equipment
	CM (31-33)	Other manufacturing, repair and installation
	DE (35-39)	**Electricity, gas, water; sewerage and waste management**
Construction	41	Construction of buildings
	42	Civil engineering
	43	Specialised construction activities

Macro sector	Industry code	Industry name
Services	**G (45-47)**	**Wholesale and retail trade; repair of motor vehicles**
	45	Motor trades
	46	Wholesale trade
	47	Retail trade
	H (49-53)	**Transportation and storage**
	49-51	Land, water and air transport
	52	Warehousing and transport support activities
	53	Postal and courier activities
	I (55-56)	**Accommodation and food service activities**
	55	Accommodation
	56	Food and beverage service activities
	J (58-63)	**Information and communication**
	58-60	Publishing; film and TV production and broadcasting
	61-63	Telecommunications; information technology
	K (64-66)	**Financial and insurance activities**
	64	Financial service activities
	65-66	Insurance, pension funding and auxiliary financial activities
	L (68)	**Real estate activities**
	68IMP	Owner-occupiers' imputed rental
	68	Real estate activities, excluding imputed rental
	M (69-75)	**Professional, scientific and technical activities**
	69	Legal and accounting activities
	70	Head offices and management consultancy
	71	Architectural and engineering activities
	72-73	Research and development; advertising and market research
	74	Other professional, scientific and technical activities
	75	Veterinary activities
	N (77-82)	**Administrative and support service activities**
	77	Rental and leasing activities
	78-80	Employment activities; tourism and security services
	81	Services to buildings and landscape activities
	82	Office administration and business support activities
	O (84)	**Public administration and defence**
	P (85)	**Education**
	Q (86-88)	**Human health and social work activities**
	86	Human health activities
	87	Residential care activities
	88	Social work activities
	R (90-93)	**Arts, entertainment and recreation**
	90-91	Creative, arts, entertainment and cultural activities
	92-93	Gambling and betting; sports and recreation activities
	S (94-96)	**Other service activities**
	94	Activities of membership organisations
	95	Repair of computers, personal and household goods
	96	Other personal service activities
	T (97-98)	**Activities of households**

Annex VII - Expenditure on Adaptation is Declining

Go back



Annex VIII - Flood Defences in England

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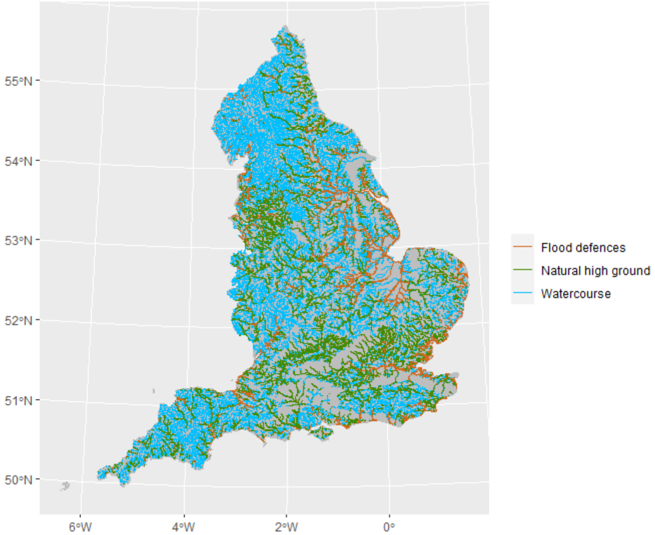


Annex IX - Instrumental Variable Conditions

Go back

- **Relevance**: rain is a good predictor of flooding
  - Floods are triggered by heavy rainfall (Environment Agency, 2009; IPCC, 2021)
  - Rainfall as a proxy for floods (Heinen et al., 2019; Akyapi et al., 2022; Kabundi et al., 2022; Crofils et al., 2023)
- **Exclusion restriction**: $P^z_{i,t}$ affects $y_{i,t+h}$ only through $f_{i,t}$
  - Direct effects only through agricultural and energy sectors (Miguel et al, 2004; Barrios et al., 2010). Channels not at play in England

Annex X - Lead-Lag Exogeneity (Stock and Watson, 2018)

Go back

LP-IV must satisfy a third condition:

- **Lead-lag exoegeneity**: $\mathbb{E}(f_{i,t+h} P^z_{i,t}) = 0$ for $h \neq 0$
  - If $P^z_{i,t}$ is to identify the effect of $f_{i,t}$ alone, it **must be uncorrelated with all shocks at all leads and lags**
  - Rainfall might not be orthogonal year by year, but z-scores capture unusual precipitation occurrences, **uncorrelated over time by construction**
  - Including **fixed effects** is usually enough to ensure LLE (Stock and Watson, 2018)
  - **Lead** exogeneity potentially more problematic, but **not restrictive** (Stock and Watson, 2018)

Annex XI - First Stage Regression

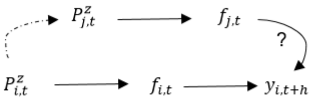
Go back

	(1)
	N. of floods
IV coefficient	3.705****
	(0.603)
F-statistic	37.75
Kleibergen-Paap	34.12
Observations	7,107

Note: The Table reports the first stage regression of the aggregate LP-IV analysis - we use the natural logarithm of GDP as our y. The dependent variable is the number of floods. We report the F-statistics and the Kleibergen-Paap rank test statistics.W include ITL3 and year fixed effects. Controls include population size and one lag of the dependent variable. Standard errors clustered at the ITL3 level are reported in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, **** $p < 0.001$

Annex XII - Floods in Neighbouring Local Authorities

- Spatial correlation potential threat to exclusion restriction
  - Moran's I $>$ 0 and can't reject positive spatial correlation



- We study the **impact of floods in neighbouring regions**. Let $S^i = \{s^1_1, s^i_2, ..., s^i_n\}$ be the set of all local authorities that share a border with i:

$$y_{i,t+h} = \alpha_i + \beta^h P^z_{i,t} + \gamma^h \sum_{j \in S^i} w_{j,t} f_{j,t} + \gamma X_{i,t} + \Theta y_{i,t-1} + \lambda_t + \varepsilon_{i,t+h}$$

where $w_{j,t}$ is j's GDP as a share of S^i's GDP

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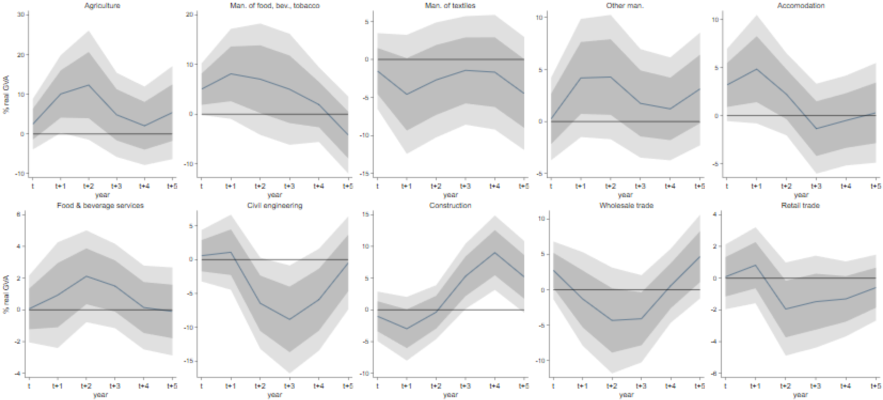
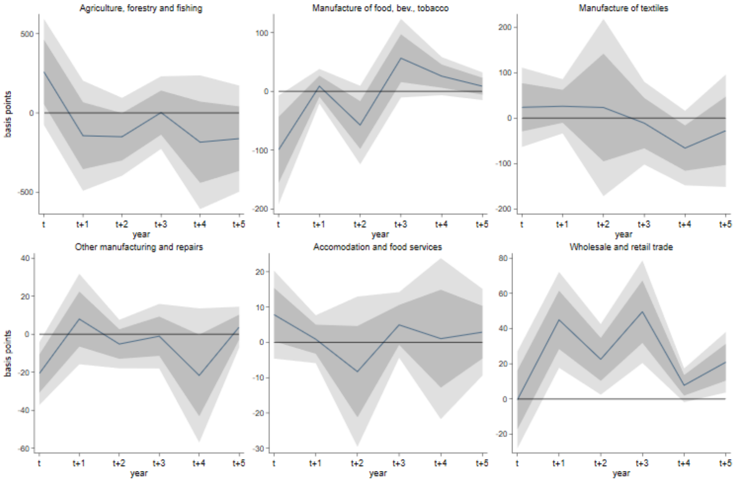
Annex XIII - Output Response to Neighbouring Floods



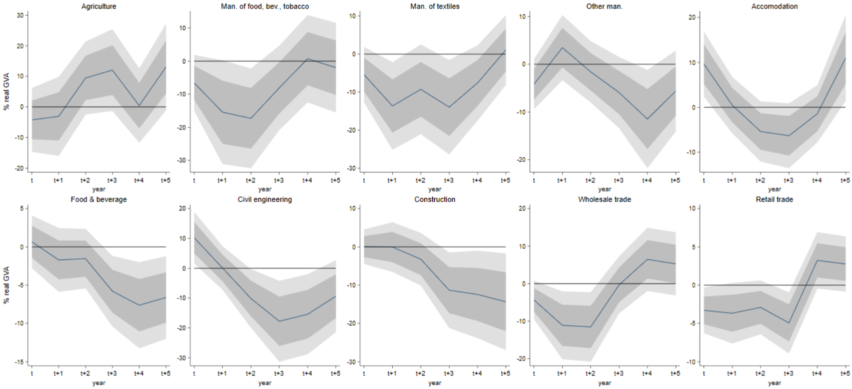
Note: Response to a 1 st. dev. increase in the number of floods in all neighbouring local authorities. Standard errors are clustered at the ITL3 level. Shaded areas denote 68% and 90% confidence bands.

Annex XIV - Inflation Response to Neighbouring Floods



Note: Response to a 1 st. dev. increase in the number of floods in all neighbouring local authorities. Standard errors are clustered at the ITL3 level. Shaded areas denote 68% and 90% confidence bands.

Annex XV - Industry Analysis: Output (All Sectors)



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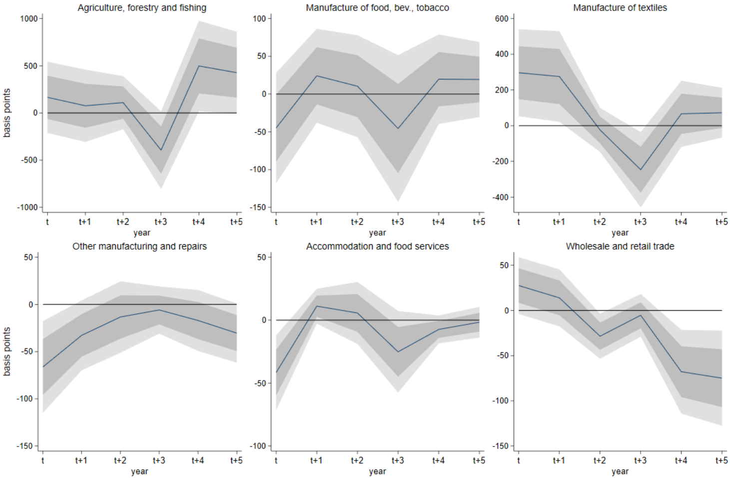
Annex XVI - Industry Analysis: Prices (All Sectors)



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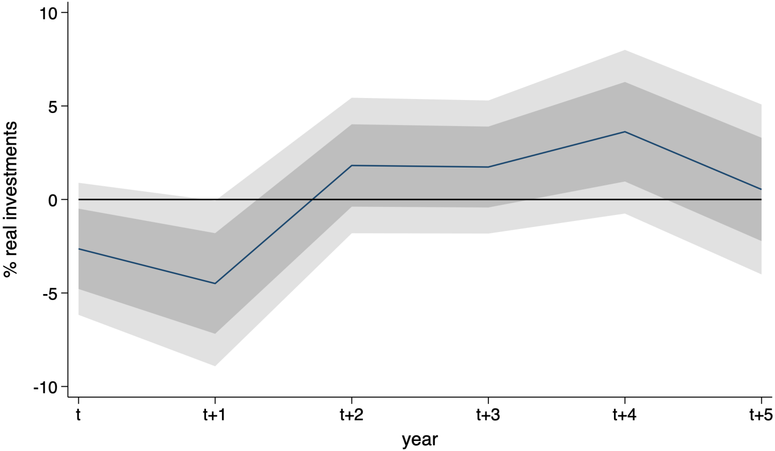
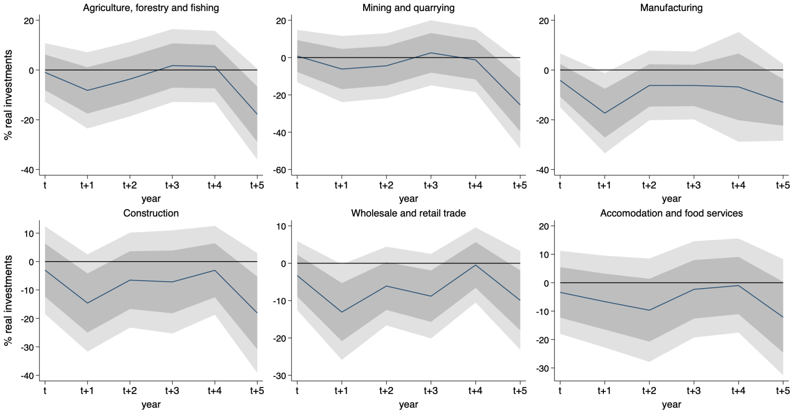
Annex XVII - IRFs of Aggregate Investments

Go back



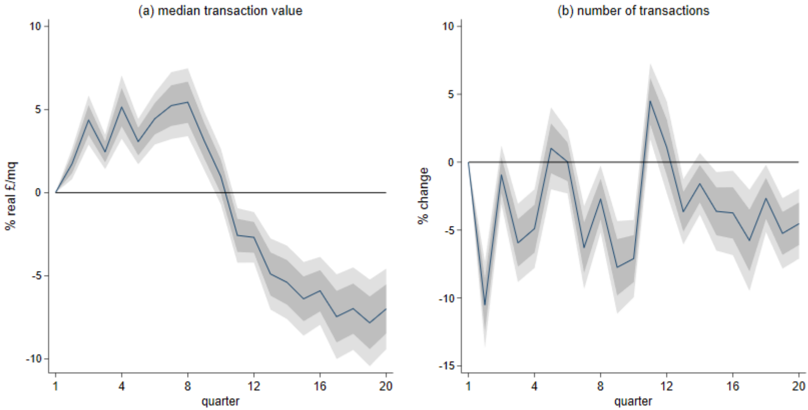
Note: Response to a 1 st. dev. increase in the number of floods. Standard errors are clustered at the ITL3 level. Shaded areas denote 68% and 90% confidence bands.

Annex XVIII - IRFs of Sectoral Investments Go back



Note: Response to a 1 st. dev. increase in the number of floods. Standard errors are clustered at the ITL3 level. Shaded areas denote 68% and 90% confidence bands.

Annex XIX - Real Estate Market Go back



Note: Response to a 1 st. dev. increase in the number of floods. Standard errors are clustered at the ITL3 level. Shaded areas denote 68% and 90% confidence bands.

Annex XX - Go back

- I-O tables to compute upstream (u_{ij}) and downstream (u_{ij}) input-output weights

$$u_{kj} = \frac{P_{kj} I_{kj}}{P_k I_k}, \quad \forall k, j; \qquad d_{kj} = \frac{P_{kj} Y_{kj}}{P_k Y_k}, \quad \forall k, j \tag{4}$$

- Then following Ghassibe (2021), we estimate **full effect**:

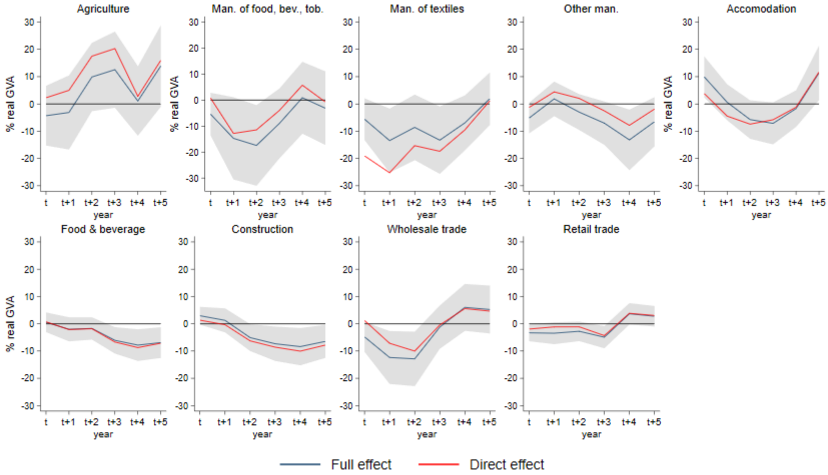
$$y^k_{i,t+h} = \alpha_i + \beta^F_{k,h} \hat{f}_{i,t} + \gamma X_{i,t} + \Theta y^k_{i,t-1} + \lambda_t + \varepsilon^F_{i,t+h}, \tag{5}$$

- and **direct effect**:

$$\begin{aligned} y^k_{i,t+h} = \alpha_i + \beta^D_{k,h} \hat{f}_{i,t} + \sum_{\tau=0}^{T} \psi^{\tau}_{k,J,N} \sum_{j=1}^{J} u_{kj} \sum_{r \in N} y^j_{r,t-\tau} \\ + \sum_{\tau=0}^{T} \phi^{\tau}_{k,J,N} \sum_{j=1}^{J} d_{kj} \sum_{r \in N} y^j_{r,t} + \gamma X_{i,t} + \lambda_t + \varepsilon^D_{i,t+h} \end{aligned} \tag{6}$$

- $(\beta^F_{k,h} - \beta^D_{k,h})$ is (lower bound) of **production network effect**

Annex XXI - Go back



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Annex XXII - Adaptation at the Extensive Margin

Go back

- Can public expenditure reduce the damage from floods?
  - Investments in **seawalls**, **stilts** or other forms of **adaptation** can reduce the damage from climate change (Fried, 2022)
  - **Countercyclical fiscal policy** can reduce the severity of economic downfall (Canova and Pappa, 2021)

- We run the following regression:

$$f_{i,t+h} = \alpha_i + \beta^h P^z_{i,t+h} + def_{i,t}(\gamma + \phi prone_i) + \Theta X_{i,t-1} + \lambda_t + \varepsilon_{i,t+h} \quad (7)$$

  - $def_{i,t}$ is either adaptation expenditure or cumulated capital
  - $prone_i = 1$ if $\overline{f}_i > \overline{f}$, 0 otherwise
  - $X_{i,t-1}$: population size, 1 lag of GDP, 3 lags of $f_{i,t}$
  - γ role of adaptation in non flood prone areas, ϕ is the difference when area is flood prone

Annex XXIII - Adaptation at the Intensive Margin

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- We compute a **state-dependent LP-IV** similar to Auerbach and Gorodnichenko (2012)'s *regime switching VAR*
  - "Dummy switch" *à la* Ramey and Zubairy (2018)
- For $h = \{0; 5\}$:

$$y_{i,t+h} = I_{i,t-1}\left[\alpha_i + \beta^h \hat{f}_{i,t} + \gamma X_{i,t} + \Theta y_{i,t-1} + \lambda_t\right] + (1 - I_{i,t-1})\left[\alpha_i + \beta^h \hat{f}_{i,t} + \gamma X_{i,t} + \Theta y_{i,t-1} + \lambda_t\right] + \varepsilon_{i,t+h} \quad (8)$$

with

$$I_{i,t-1} = \begin{cases} 1 & \text{if } exp_{i,t-1} > \overline{exp} \\ 0 & \text{otherwise} \end{cases}$$

Annex XXIV - Can Adaptation Reduce Damages? Industry Prices

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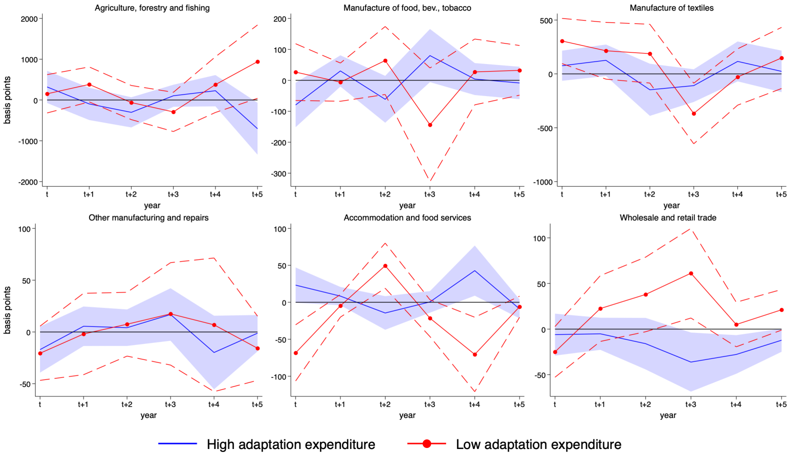

Note: Response to a 1 st. dev. increase in the number of floods. Standard errors are clustered at the ITL3 level. Shaded areas denote 90% confidence bands.

Annex XXV - Can Adaptation Reduce Damages ? Aggregate Output

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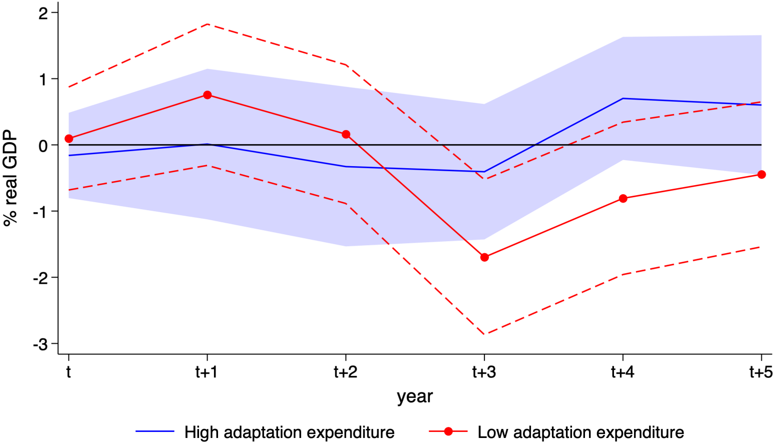

Note: Response to a 1 st. dev. increase in the number of floods. Standard errors are clustered at the ITL3 level. Shaded areas denote 90% confidence bands.

Annex XXVI - Can Adaptation Reduce Damages? Aggregate Prices

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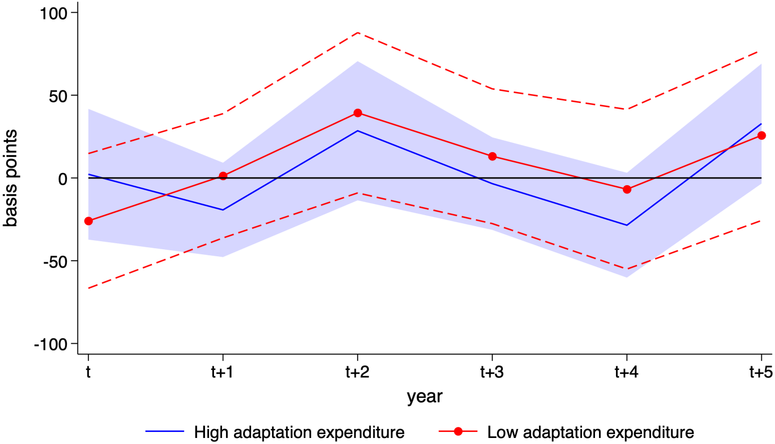

Note: Response to a 1 st. dev. increase in the number of floods. Standard errors are clustered at the ITL3 level. Shaded areas denote 90% confidence bands.