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Extreme weather events and economic activity: The case of low water levels on the Rhine river

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Martin Ademmer, Nils Jannsen,
and Saskia Mösle

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ABSTRACT

EXTREME WEATHER EVENTS AND ECONOMIC ACTIVITY: THE CASE OF LOW WATER LEVELS ON THE RHINE RIVER

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In this paper, we exploit exogenous variation in navigability of the Rhine river to analyze the impact of weather-related supply shocks on economic activity in Germany. Our analysis shows that low water levels lead to transportation disruptions that cause a significant and economically meaningful decrease of economic activity. In a month with 30 days of low water, industrial production in Germany declines by about 1 percent, ceteris paribus. Our analysis highlights the importance of extreme weather events for business cycle analysis and contributes to gauging the costs of extreme weather events in advanced economies. Furthermore, we provide a specific example for an idiosyncratic supply shock to a small sector that amplifies to an economically meaningful effect at the macroeconomic level.

Keywords: Climate, extreme weather events, low water, supply shocks, business cycle effects.

JEL classification: E32, Q54.

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Extreme weather events and economic activity: The case of low water levels on the Rhine river

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April 2020

Abstract: In this paper, we exploit exogenous variation in navigability of the Rhine river to analyze the impact of weather-related supply shocks on economic activity in Germany. Our analysis shows that low water levels lead to transportation disruptions that cause a significant and economically meaningful decrease of economic activity. In a month with 30 days of low water, industrial production in Germany declines by about 1 percent, ceteris paribus. Our analysis highlights the importance of extreme weather events for business cycle analysis and contributes to gauging the costs of extreme weather events in advanced economies. Furthermore, we provide a specific example for an idiosyncratic supply shock to a small sector that amplifies to an economically meaningful effect at the macroeconomic level.

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1. Introduction

What is the impact of extreme weather events on economic activity? A growing body of literature investigates this question by analyzing how variations in temperature, precipitation, and other weather realizations affect economic outcomes such as agricultural production, commodity prices, labor productivity, or aggregate output (see Dell et al. 2014 for an overview). Given that global climate change could increase the frequency and intensity of extreme weather events in the future (IPCC 2018), assessing their economic consequences is becoming increasingly relevant, also for macroeconomic analyses and economic policy. In this vein, several central banks have started to evaluate the consequences of climate change for the conduct of monetary policy and acknowledge that weather-related supply shocks, for instance due to droughts and heatwaves, can generate a trade-off between stabilizing inflation or output (Coeuré 2018).

In Germany, the exceptionally dry and hot summer of 2018 has fueled the debate on the economic impact of extreme weather events. The drought inter alia led to critically low water levels on the Rhine river, which severely disrupted cargo shipping on Western Europe’s most important waterway. Even though shipping on inland waterways accounts only for a small share of the total volume of transportation in Germany, it is responsible for a significant share of the transportation of industrial goods such as coal, crude oil, coke oven products, and chemical products. These goods are usually far upstream in the production chain and restrictions in the transportation of these products can thus lead to impediments in more downstream production stages, thereby potentially amplifying the overall economic effects.

In this paper, we make use of a historical database of water levels on the Rhine to analyze the impact of weather-related supply shocks on economic activity in Germany. The results of our empirical analysis show that critically low water levels on the Rhine not only significantly decrease the volume of inland water transportation but also significantly impair industrial production. We find that this effect is economically meaningful: a month with 30 days of low water levels on the Rhine dampens overall inland water transportation by about 25 percent and industrial production by about 1 percent. According to our estimates, the low water period in the second half of 2018 had a peak impact of -1.5 percent on the level of industrial production. Furthermore, our analysis allows us to quantify the effect of a transport-related supply shock on industrial production using the incidence of low water levels as an instrument. Our estimates indicate that a drop in shipping volume by 1 percent leads to a decrease in industrial production by about 0.04 percent.

Our paper contributes to the literature on the impact of extreme weather events on economic activity in several ways. First, we provide further evidence that extreme weather events can have a quantitatively meaningful impact on industrial production in advanced economies. While there is some evidence that advanced economies are significantly affected by weather events such as droughts and storms (e.g. Felbermayr and Gröschl 2014), they are usually found to be less vulnerable to weather fluctuations compared to developing economies (Dell et al. 2012; Dell et al. 2014; Hsiang 2010; Jones and Olken 2010). Our study shows that impairments of transportation infrastructure can represent an important transmission channel of how extreme weather events can dampen economic activity in advanced economies. Second, we add to the increasing literature on the short-run effects of extreme weather events or natural disasters by analyzing potential effects on a month-to-month basis. So far, most studies rely on annual data and are therefore not able to fully capture economic short-run adjustment processes following such events (Felbermayr et al. 2019). However, since economic short-run effects are of relevance for policy makers, there is increasing interest in the economic effects of extreme weather events and natural disasters at higher frequencies (Strobl 2011; Cashin et al. 2017; Heinen et al. 2019; Felbermayr et al. 2019). Third, we document that exogenous negative shocks in a very small sector of an economy can amplify to economically meaningful effects at the macroeconomic level. Therefore, from a more general perspective, our empirical findings also lend support to recent work that stresses the relevance of network effects in economies (Acemoglu et al. 2012; Acemoglu et al. 2016).[1]

The remainder of this paper is structured as follows. In the next section, we describe our data set and the empirical framework we use for assessing the economic impact of low water levels on the Rhine. In Section 3, we discuss the results of our empirical analyses and several robustness checks. Section 4 concludes.

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[1] The role of supply chain networks for the propagation and amplification of shocks has been studied more detailed by exploiting natural disasters. For example, Carvalho et al. (2016) and Todo et al. (2015) illustrate the impact of the Great East Japan Earthquake of 2011 on supply chains in Japan using firm-level data. Barrot and Sauvagnat (2016) show the relevance of supplier-customer links of US firms for the propagation of shocks in the context of natural disasters in the United States.

2. Data and empirical framework

2.1 Data

The Rhine river is the most important inland waterway in Germany and Western Europe. Approximately 80 percent of the freight transportation on inland waterways in Germany takes place on the Rhine (BDB 2019). While overall inland water transportation only accounts for about 6 percent of the total volume of transportation in Germany, it plays an important role for the transportation of many industrial goods that are often at the beginning of the production chain. For instance, around 30 percent of the transported volume of coal, crude oil and natural gas and around 20 percent of the transported volume of coking plant and petroleum products is shipped on inland waterways.

To measure the incidence of low water levels on the Rhine, we use time series data provided by the German Federal Institute for Hydrology for the water level at Kaub, a decisive gauging station in the shallowest part of the middle section of the river. All freight shipped from the seaports at the North Sea to the industrial southwest of Germany needs to pass this critical section (see Figure 1). The time series data indicate the number of days recorded in a month on which the water level measured at the Kaub gauging station was lower than 78 cm, an officially defined low water level threshold that serves as a benchmark for navigation.[2] At this gauge level ships can only carry a considerably smaller fraction of the freight compared to what they can transport at normal water levels.[3] Moreover, logistics service providers often no longer guarantee transportation services when the water level is below this threshold.

Figure 2 shows that there have been multiple incidences of such low water levels on the Rhine river since 1991. The low water period in 2018 was particularly severe. In our empirical analysis, we therefore check the robustness of our results when excluding the low water period in 2018 from our sample. As an additional robustness check, we alternatively resort to data on low water levels from another decisive gauging station of the Rhine, namely Duisburg-Ruhrort.

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[2] 78 cm corresponds to the equivalent water level which is only undercut on 20 days per year, on a long-term average. See also CCNR (2019).

[3] For example, at this gauge level in Kaub approximately four times as many ships are needed to transport the freight of one ship at a gauge level of 250 cm (Contargo 2017).

Figure 1: Map of the Rhine river and location of the gauging station Kaub.

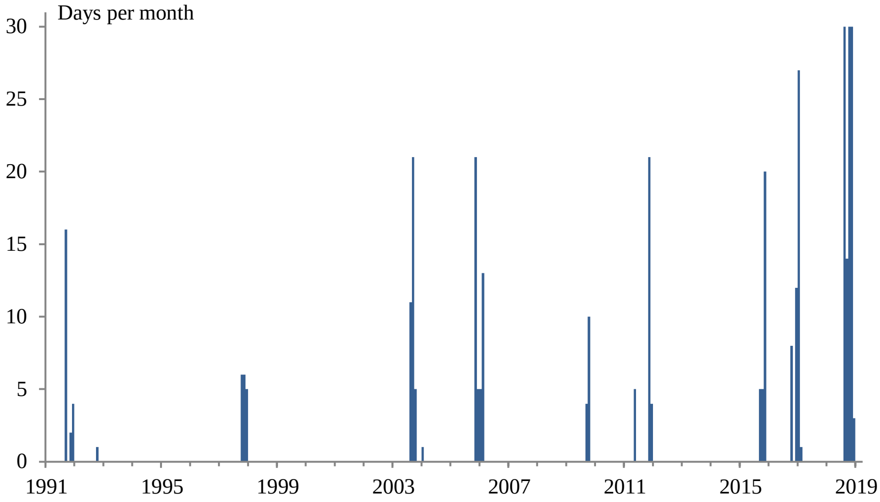

Figure 2: Incidence of low water levels on the Rhine 1991-2019.
The figure plots the number of days per month with a water level below 78cm measured at Kaub, Germany. Last value: March 2019.

To estimate the impact of low water levels on economic activity in Germany, we use monthly data for the volume of inland water transportation (measured in tons) and industrial production taken from the Federal Statistical Office of Germany.[4] As additional explanatory

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[4] We seasonally adjust the time series on the volume of inland water transportation using X-12 ARIMA since the Federal Statistical Office of Germany only provides the unadjusted series. Our results are robust if we use year-over-year growth rates of the unadjusted series instead.

variables, we use global industrial production (approximated as a GDP-weighted average of industrial production in the 46 largest economies in the world) and global trade measured as nominal global trade in goods taken from the IMF. Our sample starts in January 1991 (after the German reunification) and ends in March 2019. As monthly data on the volume of inland water transportation is only available from 1993 onwards, we convert the available annual data for the years 1991 and 1992 to monthly frequency by means of Chow-Lin interpolation. To do so, we use monthly data regarding the inland water transportation performance (measured in ton-kilometers) provided by the Federal Statistical Office of Germany as indicator variable at higher frequency.[5]

2.2 Empirical framework

We first consider the effect of low water levels on the volume of inland waterway freight transport. Specifically, we estimate

$$\mathrm{f_t} = \mathrm{a} + \sum_{\mathrm{j=0}}^{1} \mathrm{b_j}\, \Delta \mathrm{LW_{t-j}} + \mathrm{c}\, \mathrm{f_{t-1}} + \sum_{\mathrm{j=0}}^{1} \mathrm{d_j}\, \mathrm{X_{t-j}} + \mathrm{e_t}, \tag{1}$$

where $\mathrm{f_t}$ denotes the growth rate of the volume of goods transported by shipping on inland waterways in month t, $\Delta \mathrm{LW_{t-j}}$ denotes the change in the number of days with low water levels in month $t-j$, and $\mathrm{X_{t-j}}$ refers to additional explanatory variables (contemporaneous and lagged growth in global trade).[6]

Second, to analyze the effect of low water levels on industrial production, we estimate

$$\mathrm{y_t} = \alpha + \sum_{\mathrm{j=0}}^{1} \beta_{\mathrm{j}}\, \Delta \mathrm{LW_{t-j}} + \gamma\, \mathrm{y_{t-1}} + \sum_{\mathrm{j=0}}^{1} \delta_{\mathrm{j}}\, \mathrm{X_{t-j}} + \varepsilon_{\mathrm{t}}, \tag{2}$$

where $\mathrm{y_t}$ denotes the growth rate of industrial production in Germany and $\mathrm{X_{t-j}}$ refers to additional explanatory variables (contemporaneous and lagged growth in global industrial production). We include lagged values of the low water variable as well as of the additional explanatory variables in both equations to also account for possible delayed effects.

Note that we include the *change* in the number of days with low water levels as explanatory variable in equation (1) and (2). This implies that temporary periods of low water are

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[5] Our results are robust if we alternatively base our empirical analysis on a sample that starts in 1993.

[6] Including additional explanatory variables such as global trade might help explain variation in the dependent variable but should not alter the estimated effect of low water on the dependent variable given that low water is exogenous and not correlated with other explanatory variables. Omitted variable bias is therefore less of a concern for our empirical analysis.

assumed to have a temporary impact on the level of inland water transportation or the level of industrial production, respectively.[7] This seems plausible given that periods of low water occur only infrequently in our sample and are therefore unlikely to alter transportation and production structures permanently. When we compare the results of a specification in differences and in levels, we find that our preferred specification is supported by the data (Appendix A).

Third, based on the assumption that low water affects industrial production only through impaired inland water transportation, we additionally identify the causal effect of changes in the volume of transportation on the growth in industrial production. To do so, we employ a two-stage least squares (2SLS) procedure. We first regress the changes in the transportation volume on the low water variable, along the lines of equation (1). We then estimate a regression of industrial production growth on changes in the transportation volume, replacing the latter by the predicted values from the first stage.

3. Results

3.1 Low water levels and inland water transportation

Table 1 summarizes our estimates of the effects of low water levels on the Rhine on the volume of inland water transportation in Germany based on equation (1). We find that low water levels have statistically significant and quantitatively large effects on inland water transportation. According to our estimates, one additional day of low water leads to a decline in inland water transportation by about 0.9 percent, and this effect is significant at the 1 percent level (column 1). A full month (30 days) of low water therefore decreases the volume of inland water transportation by about 25 percent compared to a month with normal water levels. One period later, the impact on inland water transportation is still about half the size.

Our results are robust across several alternative specifications. Column 2 in Table 1 shows the estimated effects when we include contemporaneous and lagged growth of global trade

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[7] For instance, let us assume that there are zero days with low water in month t-1, one day with low water in month t, and again zero days with low water in month t+1. Accordingly, the growth rate of industrial production decreases ceteris paribus by β percent in month t compared to the previous month. It then increases again by β percent in month t+1, thus leaving the level of production unchanged. In contrast, a specification with the number of days with low water levels as explanatory variable would imply that a day with low water leads to a permanent reduction of the level of production.

as additional explanatory variables. The estimated parameter values are basically identical to specification 1. Column 3 shows the outcome when accounting for the contemporaneous impact of low water levels only. In comparison to specification 1, this specification results in a slightly lower but not statistically different point estimate of the contemporaneous effect. Column 4 excludes the most recent and particularly severe period of low water levels in 2018 from our sample. We find a slightly lower lagged effect of low water levels but an almost unchanged contemporaneous effect, indicating that the previous findings are not primarily driven by the most recent low water period. Finally, column 5 shows the results of using the gauge level measured at Duisburg-Ruhrort instead of the gauge level measured at Kaub as explanatory variable. Again, the estimated impact of low water levels on inland water transportation is remarkably close to the previous specifications.

Table 1: Low water levels and inland water transportation

	Growth in volume of inland water transportation				
	(1) full sample	(2) full sample	(3) full sample	(4) until 2017	(5) full sample
Δ days with low water at Kaub	-0.870***	-0.879***	-0.750***	-0.857***	
	(0.093)	(0.103)	(0.098)	(0.078)	
Δ days with low water at Kaub, t-1	-0.410***	-0.423***		-0.255***	
	(0.135)	(0.130)		(0.067)	
Growth in volume of inland water transportation, t-1	-0.403***	-0.400***	-0.276***	-0.403***	-0.381***
	(0.045)	(0.048)	(0.072)	(0.050)	(0.051)
Growth in global trade		0.237***	0.231***	0.245***	0.251***
		(0.054)	(0.056)	(0.055)	(0.056)
Growth in global trade, t-1		0.071	0.035	0.083*	0.071
		(0.048)	(0.056)	(0.046)	(0.051)
Δ days with low water at Ruhrort					-0.836***
					(0.083)
Δ days with low water at Ruhrort, t-1					-0.367***
					(0.095)
Obs.	337	337	337	322	337
Adj. R²	0.348	0.391	0.347	0.373	0.382

Notes: Robust standard errors are given in parentheses. ***/**/* indicates statistical significance at the 1%/5%/10% level.

Furthermore, we additionally investigate the effects of low water levels on the Rhine on the volume of road transportation and on the volume of rail transportation in Germany (Appendix B). In sum, we find no evidence for a considerable increase in road and rail transportation due to low water levels, which suggests that impairments in inland water shipping cannot be compensated by a noticeable shift to road and rail transportation in the short-run.

3.2 Low water levels and industrial production

Table 2 summarizes our estimates of the effects of low water levels on the Rhine on industrial production in Germany based on equation (2). We find that one additional day of low water leads to a decline in industrial production by 0.034 percent, and this effect is statistically significant at the 1 percent level (column 1). We also find that low water levels have a lagged impact on industrial production that is somewhat smaller in magnitude and less precisely measured.

These results show that low water levels have a quantitatively important effect on overall economic activity in Germany. In a month with 30 days of low water industrial production declines by about 1 percent, ceteris paribus. By means of a dynamic counterfactual analysis, we can also use the estimated effects to quantify the impact of the most recent period of low water levels over time. Accordingly, the largest impact occurred in November 2018, with the level of industrial production being 1.5 percent below the counterfactual level without low water effects.[8] Given a share of industrial production in total gross value added of about 25 percent, this corresponds to a decline in GDP of close to 0.4 percent. Moreover, since additional effects may arise due to lower value added in the (albeit very small) sector of inland water transportation and possibly due to spillover effects from the industry sector to the service sector, these calculations are likely to present a lower bound of the overall economic impact.

We again estimate several alternative specifications to check the robustness of our findings. Column 2 shows the estimated effects when we additionally include contemporaneous and lagged growth in global industrial production as explanatory variables. We find that this leaves our results almost unchanged. In accordance with the previous subsection, column 3 shows the results when accounting for the contemporaneous impact of low water levels only.

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[8] Detailed results are available upon request.

Again, when compared to column 1, this specification results in a slightly lower but not statistically different point estimate of the contemporaneous effect. Column 4 shows the results when we exclude the most recent low water period in 2018 from our sample. This leads to a slightly higher (though less precisely measured) point estimate of the impact of low water on industrial production. Finally, column 5 shows that our results do not depend on whether water levels are measured at Kaub or at Ruhrort.

Table 2: Low water levels and industrial production

	Growth in industrial production				
	(1) full sample	(2) full sample	(3) full sample	(4) until 2017	(5) full sample
Δ days with low water at Kaub	-0.034***	-0.038***	-0.029**	-0.041**	
	(0.012)	(0.012)	(0.013)	(0.017)	
Δ days with low water at Kaub, t-1	-0.024*	-0.026*		-0.036*	
	(0.014)	(0.014)		(0.019)	
Growth in industrial production, t-1	-0.172	-0.357***	-0.346***	-0.360***	-0.358***
	(0.119)	(0.043)	(0.044)	(0.044)	(0.042)
Growth in global industrial production		1.177***	1.188***	1.188***	1.178***
		(0.110)	(0.110)	(0.112)	(0.109)
Growth in global industrial production, t-1		0.553***	0.529***	0.545***	0.556***
		(0.169)	(0.170)	(0.174)	(0.169)
Δ days with low water at Ruhrort					-0.034**
					(0.014)
Δ days with low water at Ruhrort, t-1					-0.027**
					(0.013)
Obs.	337	337	337	322	337
Adj. R^2	0.032	0.342	0.338	0.349	0.342

Notes: Robust standard errors are given in parentheses. ***/**/* indicates statistical significance at the 1%/5%/10% level.

3.3 Transportation disruptions and industrial production

Finally, we exploit the exogenous variation in low water levels to examine the causal effect of transport-related supply shocks on industrial production. To that end, we use an instrumental approach to estimate the effect of growth in the volume of inland water transportation on growth in industrial production. The change in the number of days with low water serves as our instrument, the relevance of which has been shown in Table 1.[9]

The 2SLS estimates are presented in Table 3. Our results indicate that a decline in inland water transportation by 1 percent leads to a decline in industrial production by 0.036 percent in the same month (column 1). In the following month, industrial production growth is still dampened by a roughly similar magnitude. Again, the results do not change considerably when we add contemporaneous and lagged growth in global industrial production as additional explanatory variables and when we exclude the most recent period of low water levels in 2018 from our sample (columns 2 and 3, respectively).

Table 3: Inland water transportation and industrial production

	Growth in industrial production			
	(1) 2SLS full sample	(2) 2SLS full sample	(3) 2SLS until 2017	(4) LS full sample
Growth in volume of inland water transportation	0.036***	0.040***	0.042*	0.051***
	(0.014)	(0.014)	(0.022)	(0.013)
Growth in volume of inland water transportation, t-1	0.027***	0.030***	0.034***	0.032***
	(0.010)	(0.009)	(0.011)	(0.010)
Growth in industrial production, t-1	-0.184	-0.361***	-0.364***	-0.182
	(0.114)	(0.041)	(0.043)	(0.113)
Additional explanatory variables	no	yes	yes	no
Obs.	337	337	322	337
Adj. R²	0.086	0.370	0.380	0.091

Notes: Robust standard errors are given in parentheses. ***/**/* indicates statistical significance at the 1%/5%/10% level.

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[9] More specifically, the instrument list of the baseline specification includes the change in the number of days with low water, the lagged change in the number of days with low water, lagged growth of the transportation volume, lagged growth of industrial production, and a constant. The first-stage *F*-statistic is well above 10, which indicates that our instruments are strong.

For comparison, we additionally show the corresponding least squares estimates (column 4). They are somewhat larger in magnitude, which is reasonable given that there is a positive, simultaneous relationship between the transportation volume and industrial production. The 2SLS regression controls for the endogeneity of the transportation volume and therefore leads to smaller coefficient estimates.

In general, our results illustrate that exogenous shocks to a rather small sector in an economy (the share of inland water transportation in total gross value added in Germany is below 0.2 percent) can bring about sizable effects in other sectors. They also amplify to relevant fluctuations at the macroeconomic level. For example, an exogenously caused decline in the volume of inland water transportation by 10 percent dampens industrial production by about 0.4 percent in the same month. Given a share of the industrial sector of about 25 percent in total value added, these spillover effects alone could lead to a decline by about 0.1 percent in GDP.[10] Again, this is the case even though from a macroeconomic perspective the direct impact of the shock on value added in the inland water transportation sector is rather negligible. The results of our analysis therefore also underline the relevance of network effects in economies (Acemoglu et al. 2012; Acemoglu et al. 2016).

4. Conclusion

In this paper, we exploit exogenous variation in navigability of the Rhine river to analyze the impact of weather-related supply shocks on economic activity in Germany. The Rhine is the most important inland waterway in Germany and Western Europe, carrying approximately 80 percent of the freight transport on inland waterways in the country. Our analysis makes use of water level data from 1991 to 2019 and shows that low water levels lead to transportation disruptions that cause a significant and economically meaningful decrease of industrial production. In a month with 30 days of low water, industrial production in Germany declines by about 1 percent, ceteris paribus.

Our study highlights the importance of extreme weather events for business cycle analysis by providing empirical evidence for sizable short-run effects on economic activity. In this regard, we show that the drought in 2018 played an important role for the slowdown of the

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[10] This approximation assumes that changes in inland water transportation and industrial production (which is measured in terms of production value) are good proxies for changes in the gross value added of the respective sectors.

German economy in that year. Thus, our study helps gauging the potential costs of extreme weather events in advanced economies. It also helps to better disentangle temporary fluctuations from permanent effects, which is important for the conduct of monetary and fiscal policy. Moreover, our results show that exogenous disruptions in a very small sector of the economy, such as inland water transportation, can amplify to quantitatively meaningful effects at the macroeconomic level. Emphasizing the relevance of network effects, our study provides a specific example for an idiosyncratic sectoral supply shock that considerably spreads to the rest of the economy.

Appendix

Appendix A: Specification in differences versus levels

In this Appendix, we compare a specification with the number of days ($\mathrm{LW}_{\mathrm{t-j}}$) as explanatory variable to our baseline specification with the change in the number of days ($\Delta\mathrm{LW}_{\mathrm{t-j}}$) as explanatory variable. The former specification is given by

$$\mathrm{y_t} = \alpha + \textstyle\sum_{\mathrm{j=0}}^{\mathrm{J}} \theta_{\mathrm{j}}\, \mathrm{LW}_{\mathrm{t-j}} + \gamma\, \mathrm{y}_{\mathrm{t-1}} + \epsilon_{\mathrm{t}}. \tag{A1}$$

The resulting estimates are shown in Table A1, column 1 to 3. The first column shows the results for $J = 1$ without including a lagged dependent variable, the second column shows the results for the same specification with $J = 2$, and the third column shows the results for $J = 2$ including a lagged dependent variable. For comparison, the corresponding estimates with the change in the number of days are taken from Table 2 and again shown in column 4. It turns out that the estimated coefficients θ_1 and θ_2 are positive. We then test the hypothesis $\sum_{\mathrm{j=0}}^{\mathrm{J}} \theta_{\mathrm{j}} = 0$, which is implicit in our assumption of low water levels having only a temporary impact on the level of industrial production. We find that standard Wald tests cannot reject this hypothesis (with p-values in the range from 0.6 to 0.8). In addition, the Akaike Information Criterion (AIC) slightly favors our baseline specification.

Table A1: Low water levels and industrial production (differences vs. levels)

	Growth in industrial production			
	(1) full sample	(2) full sample	(3) full sample	(4) full sample
Δ days with low water at Kaub				-0.034***
				(0.012)
Δ days with low water at Kaub, t-1				-0.024*
				(0.014)
Growth in industrial production, t-1			-0.172	-0.172
			(0.119)	(0.119)
Days with low water at Kaub	-0.028***	-0.030***	-0.031***	
	(0.010)	(0.010)	(0.010)	
Days with low water at Kaub, t-1	0.026	0.017	0.012	
	(0.016)	(0.018)	(0.018)	
Days with low water at Kaub, t-2		0.023	0.027	
		(0.017)	(0.017)	
Obs.	337	337	337	337
AIC	3.544	3.546	3.517	3.511

Notes: Robust standard errors are given in parentheses. ***/**/* indicates statistical significance at the 1%/5%/10% level.

Appendix B: Low water levels and alternative means of transportation

In this Appendix, we consider the effect of low water on the volume of goods transported by road and rail. This allows us to gain some insight into the degree of substitution between inland water transportation and road and rail traffic. Due to data availability reasons, the regressions are based on a sample period that starts in 1997 and 2005, respectively.

The resulting estimates are shown in Table B1. We find a positive response of growth in road transportation to low water levels on the Rhine, but this response is very small and statistically not distinguishable from zero. As shown in column 2, the response of growth in road transportation to a change in global trade is very similar to the response of growth in inland water transportation that we previously found in Table 1. The response of rail transportation is statistically distinguishable from zero but even smaller in magnitude than the response of road transportation (Table B1, column 3). Accordingly, one additional day of low water causes rail transportation to increase only by about 0.07 percent. Given that the overall volume of goods transported by rail is only slightly higher than the volume of goods transported on inland waterways, this small increase can therefore barely compensate for the decline in inland water transportation.

Table B1: Low water levels and road and rail transportation

	Growth in volume of road transportation		Growth in volume of rail transportation	
	(1) 1997-2019	(2) 1997-2019	(3) 2005-2019	(4) 2005-2019
Δ days with low water at Kaub	0.081	0.073	0.071**	0.067**
	(0.066)	(0.053)	(0.029)	(0.030)
Δ days with low water at Kaub, t-1	0.105	0.094	-0.007	-0.008
	(0.125)	(0.096)	(0.082)	(0.081)
Growth in road/rail transportation, t-1	-0.506***	-0.484***	-0.493***	-0.475***
	(0.040)	(0.044)	(0.049)	(0.049)
Growth in global trade		0.266***		0.161***
		(0.072)		(0.059)
Growth in global trade, t-1		0.031		0.045
		(0.089)		(0.075)
Obs.	262	262	171	171
Adj. R^2	0.252	0.285	0.244	0.269

Notes: Robust standard errors are given in parentheses. ***/**/* indicates statistical significance at the 1%/5%/10% level.

References

Acemoglu, D., Akcigit, U. and W. Kerr (2016). Networks and the Macroeconomy: An Empirical Exploration. In: National Bureau of Economic Research Macroeconomics Annual (M. Eichenbaum and J. Parker, eds.), 30: 276–335. University of Chicago Press.

Acemoglu, D., Carvalho, V., Ozdaglar, A. and A. Tahbaz-Salehi (2012). The Network Origins of Aggregate Fluctuations. *Econometrica* 80: 1977–2016.

Barrot, J.-N. and J. Sauvagnat (2016). Input Specificity and the Propagation of Idiosyncratic Shocks in Production Networks. *The Quarterly Journal of Economics* 113(3): 1543–1592.

BDB – Bundesverband der Deutschen Binnenschifffahrt e.V. (2019). Daten und Fakten 2018/2019. Available online <https://www.binnenschiff.de/service/daten-fakten> (07.01.2020).

Carvalho, V.M., M. Nirei, Y.U. Saito, and A. Tahbaz-Salehi (2016). Supply Chain Disruptions: Evidence from the Great East Japan Earthquake, Policy Research Institute, Ministry of Finance Japan, Discussion papers 287.

Cashin, P., Mohaddes, K. and M. Raissi (2017). Fair weather or foul? The macroeconomic effects of El Niño. *Journal of International Economics* 106: 37-54.

CCNR – Central Commission for the Navigation of the Rhine (2019). Annual Report 2019: Inland Navigation in Europe – Market Observation. Available online <https://www.ccr-zkr.org/files/documents/om/om19_II_en.pdf#search=%22low%20water%20discharge%22> (07.01.2020).

Coeuré, B. (2018). Monetary policy and climate change. Speech at the conference on "Scaling up Green Finance: The Role of Central Banks", organised by the Network for Greening the Financial System, the Deutsche Bundesbank, and the Council on Economic Policies, Berlin, 8 November.

Contargo (2017). Low Water. Available online <https://www.contargo.net/assets/pdf/Kleinwasser_Info-2017-EN.pdf> (07.01.2020).

Dell, M., Jones, B., & Olken, B. (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics,* 4(3), 66-95.

Dell M., Jones B. and B. Olken (2014). What Do We Learn from the Weather? The New Climate-Economy Literature. *Journal of Economic Literature* 52(3): 740-798.

Felbermayr, G., and J. Gröschl (2014). Naturally negative: the growth effects of natural disasters. *Journal of Development Economics* 111: 92–106.

Felbermayr, G., Gröschl, J. and B. Heid (2019). The Short-Run Trade Effects of Natural Disasters. Mimeo.

Heinen, A., Khadan, H. and E. Strobl, The Price Impact of Extreme Weather in Developing Countries, *The Economic Journal* 129 (619) 1327-1342.

Hsiang, S. (2010). Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America. *Proceedings of the National Academy of Sciences*, 107(35), 15367-15372.

IPCC (2018): Global warming of 1.5°C. [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R.Shukla,A. Pirani, W. Moufouma-Okia, C.Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X.

Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (eds.)]. Available online: <https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf>

Jones B. and B. Olken (2010). Climate Shocks and Exports. *The American Economic Review: Papers and Proceedings* 100: 454-459.

Strobl, E. (2011). The Economic Growth Impact of Hurricanes: Evidence from U.S. Coastal Counties. *Review of Economics and Statistics*, 93(2):575–589.

Todo, Y., Nakajima, K., and P. Matous (2015). How do supply chain networks affect the resilience of firms to natural disasters? Evidence from the great east Japan Earthquake. *Journal of Regional Science*, 55(2):209-229.