Supplementary Material

Environmental Inequality and Residential Sorting in Germany: A Spatial Time-Series Analysis on the Demographic Consequences of Industrial Sites

Supplement S1.   Descriptives

Table S1.1. Summary statistics

	West		East		Overall	
	Mean	SD	Mean	SD	Mean	SD
Number industrial facilities	1.29	(3.39)	1.3	(3.7)	1.29	(3.46)
Relative rank	3.88	(2.1)	3.89	(2.17)	3.88	(2.12)
Income tax revenue	409.39	(142.29)	198.83	(69.01)	363.59	(156.28)
Trade tax revenue	403.02	(717.14)	252.9	(425.95)	370.37	(667.62)
Percent foreigners (proxy)	13.55	(9.13)	2.24	(2.69)	11.09	(9.41)
Percent 65 and older	20.39	(3.05)	23.9	(3.44)	21.16	(3.46)
Percent 18 and younger	17.45	(1.91)	14.06	(1.73)	16.71	(2.34)
Population density	307.14	(394.7)	178.2	(271.75)	279.1	(375.22)
N.Obs.	34860		9690		44550	

Supplement S2. Rank event time function

(a) Increase

(b) Decrease
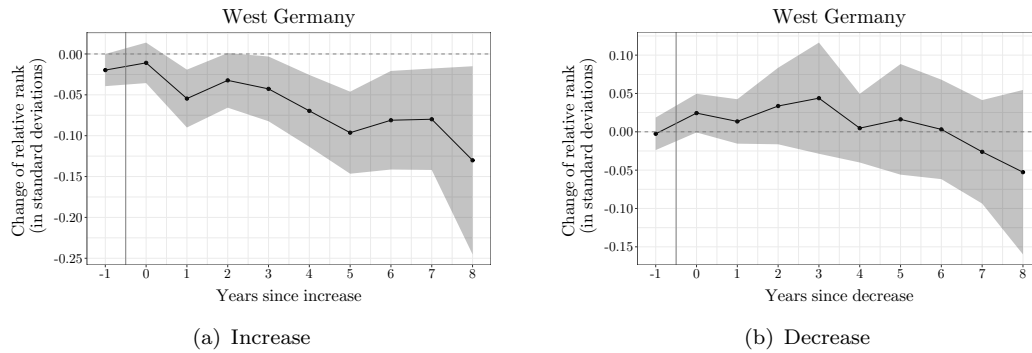
Figure S2.1. Effect estimates of rank reordering ($\geq |1|$ rank) and time paths in West Germany based on FEIS estimate with cluster robust 95% confidence intervals.

(a) Increase

(b) Decrease
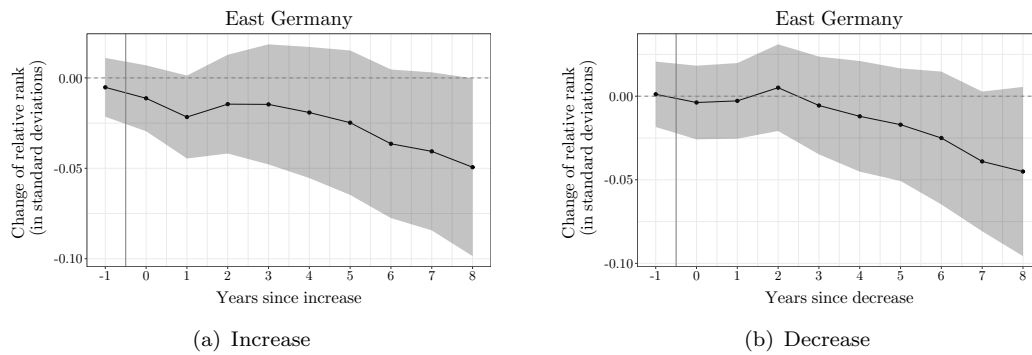
Figure S2.2. Effect estimates of rank reordering ($\geq |1|$ rank) and time paths in East Germany based on FEIS estimate with cluster robust 95% confidence intervals.

Supplement S3.   Conventional Fixed Effects models

**Table S3.2.** Fixed effects (FE) estimator. Dep. var.: Number of industrial facilities

	Overall	West	East
	(1)	(2)	(3)
Income tax revenue$_{t-1}$	-0.017^*	-0.009	$-0.045^\dagger$
	(0.007)	(0.007)	(0.027)
W Income tax revenue$_{t-1}$	0.028^{**}	0.015	0.132^*
	(0.010)	(0.010)	(0.059)
Controls	Yes	Yes	Yes
R^2	0.021	0.018	0.039
Adj. R^2	-0.103	-0.105	-0.085
Num. obs.	40095	31374	8721

$^{***}p < 0.001$, $^{**}p < 0.01$, $^*p < 0.05$, $^\dagger p < 0.1$. Standardized coefficients. Cluster robust standard errors in parentheses. W is the spatially lagged coefficient. Controls: % aged 18 or younger, % aged 65 or above, population density, population density^2, % of foreigners, trade tax revenue per capita, trade tax revenue per capita^2, year dummies (except year, all additionally included as spatial lag).

Table S3.3. Fixed effects (FE) estimator. Dep. var.: Income tax revenue

|	Overall	West	East	Overall	West	East
	(1)	(2)	(3)	(4)	(5)	(6)
Number facilities$_{t-1}$	-0.115^{***}	-0.166^{***}	0.006			
	(0.033)	(0.044)	(0.014)			
W Number facilities$_{t-1}$	0.228^{**}	$0.230^\dagger$	0.239^{***}			
	(0.087)	(0.139)	(0.036)			
Relative rank$_{t-1}$				-0.012	-0.014	-0.005
				(0.028)	(0.038)	(0.009)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.455	0.445	0.954	0.451	0.443	0.944
Adj. R^2	0.386	0.376	0.948	0.382	0.373	0.936
Num. obs.	40095	31374	8721	40095	31374	8721

$^{***}p < 0.001$, $^{**}p < 0.01$, $^*p < 0.05$, $^\dagger p < 0.1$. Standardized coefficients. Cluster robust standard errors in parentheses. W is the spatially lagged coefficient. Controls: % aged 18 or younger, % aged 65 or above, population density, population density^2, % of foreigners, trade tax revenue per capita, trade tax revenue per capita^2 year dummies (except year, all additionally included as spatial lag in models 1 - 3).
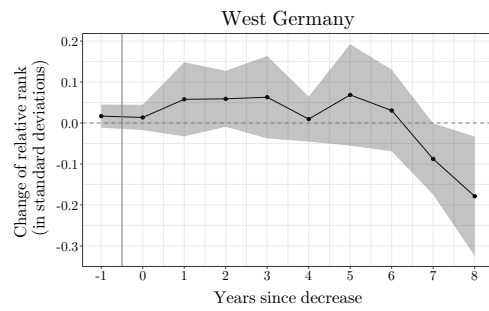
(a) Increase

(b) Decrease
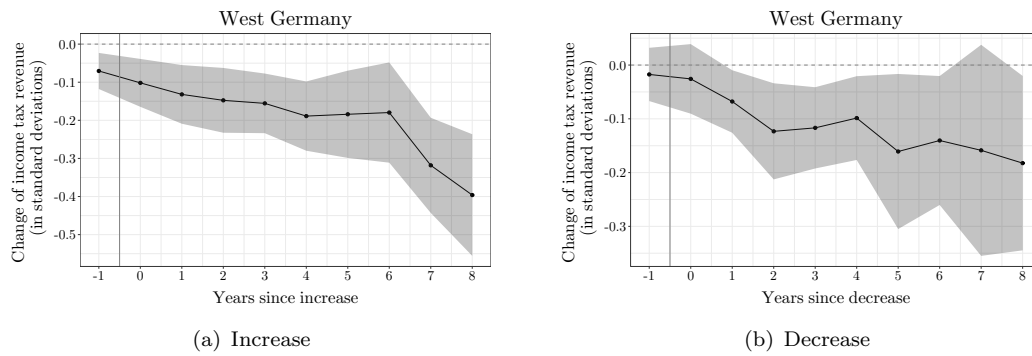
Figure S3.3. Effect estimates of dichotomous shocks ($\geq |0.9|$) and time paths in West Germany based on FE SLX estimate with cluster robust 95% confidence intervals.

(a) Increase
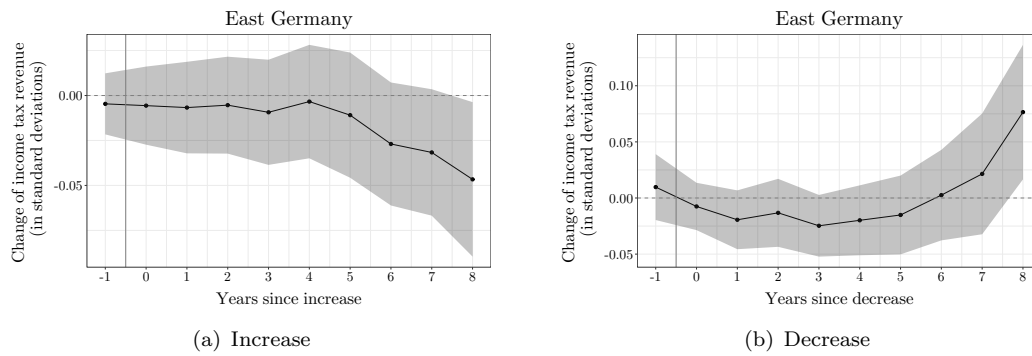
(b) Decrease

Figure S3.4. Effect estimates of dichotomous shocks ($\geq |0.9|$) and time paths in East Germany based on FE SLX estimate with cluster robust 95% confidence intervals.
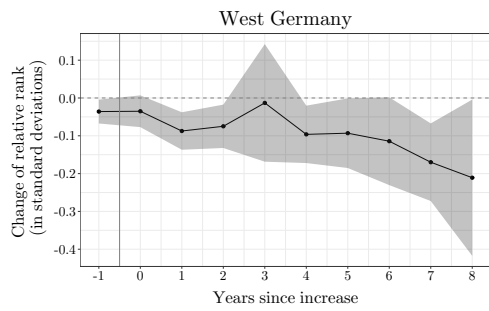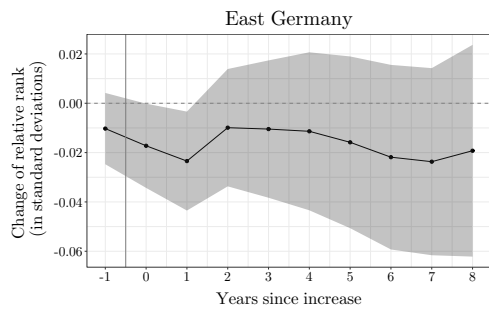
(a) Increase

(b) Decrease

Figure S3.5. Effect estimates of rank reordering ($\geq |1|$ rank) and time paths in West Germany based on FEIS estimate with cluster robust 95% confidence intervals.

(a) Increase
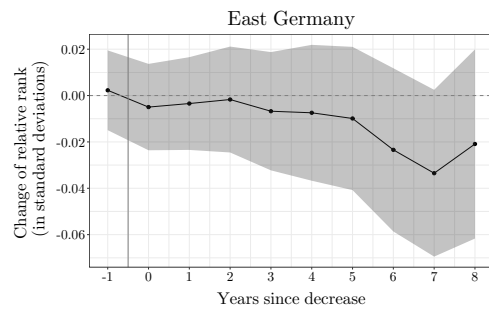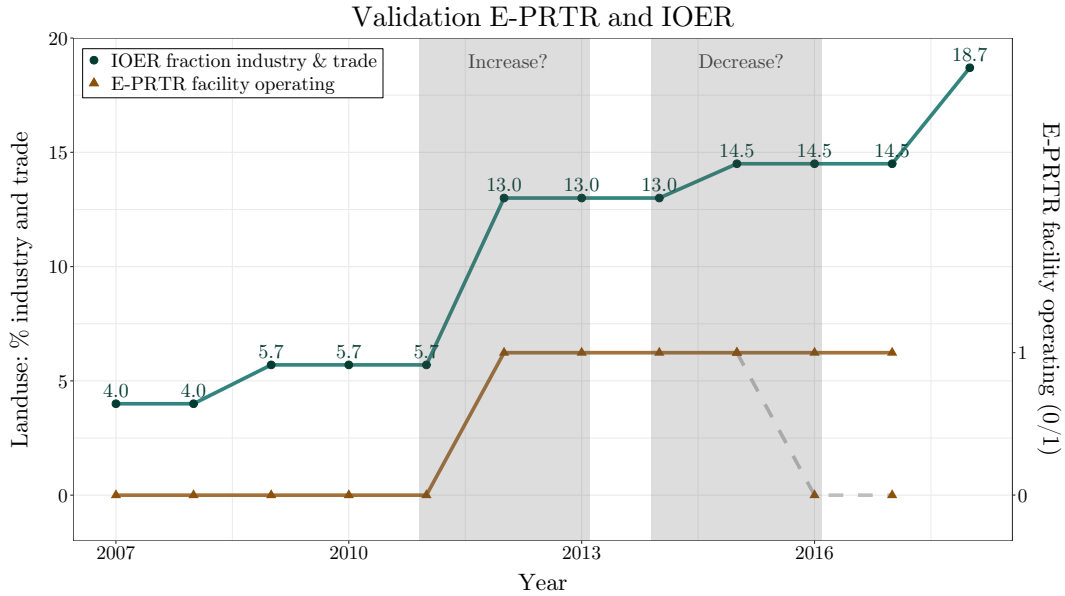
(b) Decrease

Figure S3.6. Effect estimates of rank reordering ($\geq |1|$ rank) and time paths in East Germany based on FEIS estimate with cluster robust 95% confidence intervals.

Supplement S4. Validation strategy

Figure S4.7. Example of validation strategy for placement of new and closing of old industrial facilities. Dashed line with triangles shows the raw information on facility operation, the solid line shows the corrected data.

We validate the changes in industrial facilities based on the E-PRTR (European Commission, 2006) against land-use data based on the IOER monitor (Meinel, 2011). For a 1×1km grid over Germany, the IOER monitor provides information on the share of land-use for industry and trade.

For each E-PRTR facility location, we allocated the respective land-use information from 2007 to 2018 based on the geographic coordinates. Subsequently, we evaluated the changes in land-use around the opening or closing of the facility according to E-PRTR. Therefore, we use the respective year as well as the year before and after the indicated year, to allow for potential time lags in the data. For instance, the facility in Figure S4.7 started to operate in 2012 and was closed again in 2015 according to E-PRTR (brown line with triangles). So, we look at the IOER land-use data around these years (marked in grey) and check if industrial land-use increased in 2012 and decreased in 2015. In this example, we find that industrial land-use increased in 2012, thus supporting the operation start in 2012. However, industrial land-use did not decrease around 2015, thus indicating that the facility continued operating even though it dropped from the E-PRTR. We thus assume that the facility was not closed, and correct the data by recoding the operation period from 2012 to 2017 (the end of our operation period). Similarly, we would correct the starting point if not conform to increases in industrial land-use.

Supplement S5.   Results without validation

Table S5.4.   SLX between estimator. Dep. var.: Number of industrial facilities

	Overall		West		East	
	(1)	(2)	(3)	(4)	(5)	(6)
Income tax revenue	-0.414^{***}	-0.183^{***}	-0.445^{***}	-0.228^{***}	-0.100	0.012
	(0.052)	(0.044)	(0.054)	(0.046)	(0.163)	(0.125)
W Income tax revenue	0.465^{***}	-0.073	0.476^{***}	-0.078	0.727^{***}	0.052
	(0.056)	(0.051)	(0.061)	(0.055)	(0.197)	(0.160)
Controls	No	Yes	No	Yes	No	Yes
R^2	0.016	0.387	0.019	0.385	0.027	0.593
Adj. R^2	0.015	0.385	0.019	0.382	0.025	0.587
Num. obs.	4455	4455	3486	3486	969	969

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, $^{\dagger}p < 0.1$. Standardized coeffcients. Standard errors in parentheses. W is the spatially lagged coefficient. Controls: % aged 18 or younger, % aged 65 or above, population density, population density^2, % of foreigners, trade tax revenue per capita, trade tax revenue per capita^2 (all additionally included as spatial lag).

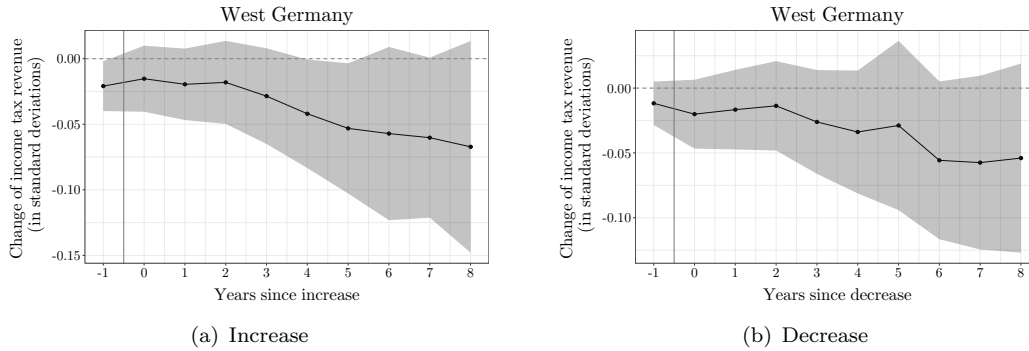**Table S5.5.**   Fixed effects individual slopes (FEIS) estimator. Dep. var.: Number of industrial facilities

	Overall	West	East
	(1)	(2)	(3)
Income tax revenue$_{t-1}$	-0.008	-0.007	0.004
	(0.012)	(0.012)	(0.053)
W Income tax revenue$_{t-1}$	0.026	0.019	0.131
	(0.016)	(0.016)	(0.120)
Controls	Yes	Yes	Yes
R^2	0.009	0.006	0.028
Adj. R^2	0.009	0.006	0.026
Num. obs.	40095	31374	8721
Num. groups: id	4455	3486	969

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, $^{\dagger}p < 0.1$. Standardized coefficients. Cluster robust standard errors in parentheses. W is the spatially lagged coefficient. Controls: % aged 18 or younger, % aged 65 or above, population density, population density^2, % of foreigners, year dummies (except year, all additionally included as spatial lag). Slopes for FEIS: trade tax revenue per capita, trade tax revenue per capita^2.

Table S5.6. Fixed effects individual slopes (FEIS) estimator Dep. var.: Income tax revenue

	Overall	West	East	Overall	West	East
	(1)	(2)	(3)	(4)	(5)	(6)
Number facilities$_{t-1}$	−0.011	−0.024*	0.010†			
	(0.008)	(0.012)	(0.005)			
W Number facilities$_{t-1}$	0.048*	0.036	0.080***			
	(0.020)	(0.030)	(0.018)			
Relative rank$_{t-1}$				−0.008†	−0.011†	−0.002
				(0.005)	(0.006)	(0.004)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.736	0.716	0.942	0.729	0.710	0.933
Adj. R^2	0.736	0.716	0.942	0.728	0.710	0.933
Num. obs.	40095	31374	8721	40095	31374	8721
Num. groups: id	4455	3486	969	4455	3486	969

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$, $^\dagger p < 0.1$. Standardized coefficients. Cluster robust standard errors in parentheses. W is the spatially lagged coefficient. Controls: % aged 18 or younger, % aged 65 or above, population density, population density^2, % of foreigners, year dummies (except year, all additionally included as spatial lag in models 1 - 3). Slopes for FEIS: trade tax revenue per capita, trade tax revenue per capita^2.

(a) Increase   (b) Decrease

Figure S5.8. Effect estimates of dichotomous shocks ($\geq |0.9|$) and time paths in West Germany based on FEIS SLX estimate with cluster robust 95% confidence intervals.

(a) Increase   (b) Decrease
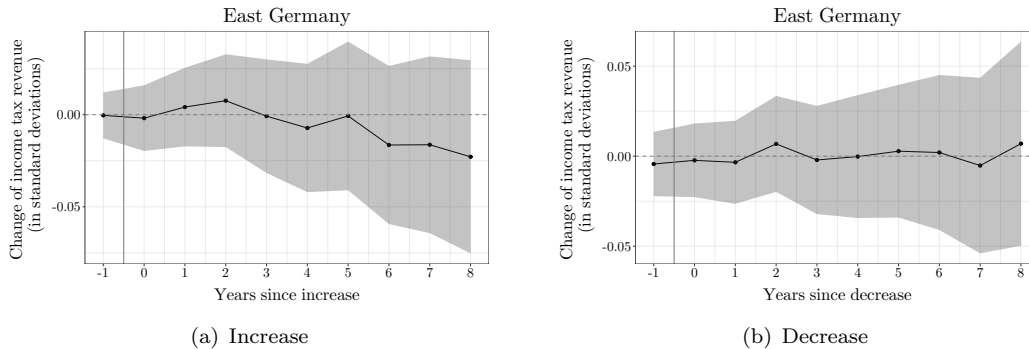
Figure S5.9. Effect estimates of dichotomous shocks ($\geq |0.9|$) and time paths in East Germany based on FEIS SLX estimate with cluster robust 95% confidence intervals.
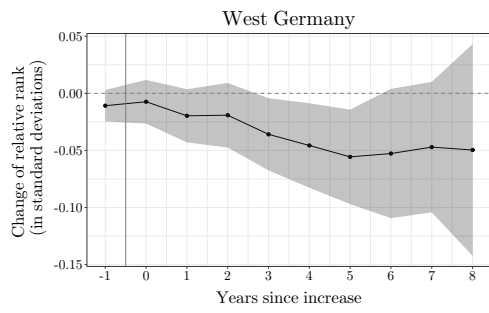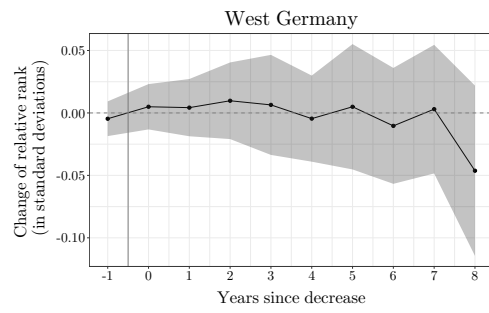
(a) Increase

(b) Decrease

Figure S5.10. Effect estimates of rank reordering ($\geq |1|$ rank) and time paths in West Germany based on FEIS estimate with cluster robust 95% confidence intervals.
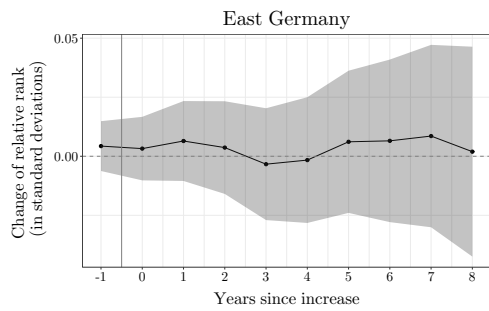

(a) Increase
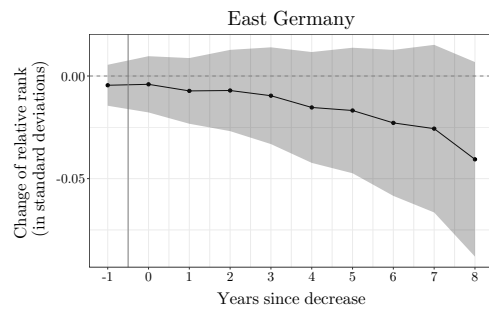
(b) Decrease

Figure S5.11. Effect estimates of rank reordering ($\geq |1|$ rank) and time paths in East Germany based on FEIS estimate with cluster robust 95% confidence intervals.

Supplement S6. Toxicity weighted air pollution

For the following results, we used the toxicity weighted emissions to air by E-PRTR facilities. For toxicity weighting, we use USETox Endpoint human health characterization factors based on total health risk of emissions to urban air. The final toxic air pollution per km^2 is computed as

$$pollution_i = (\sum_{p=1}^{P} toxweight_p * emissions_p)/area_i,$$

for each pollutant p and municipality i. As in the main analysis, the emissions of each facility were allocated to the respective municipalities by the proportionate overlap of a 1km buffer around each facility and each municipality's geographic boundaries. For missing emission record within two valid emission records linear interpolation was performed. Note, however, that we cannot impute values for cases in which E-PRTR records are missing from the beginning / to the end of the observation period even tough validation with land-use indicated the facility was present. Results are nearly identical without any imputation (not shown).

Table S6.7. SLX between estimator. Dep. var.: Toxicity-weighted air pollution

	Overall		West		East	
	(1)	(2)	(3)	(4)	(5)	(6)
Income tax revenue	-0.140**	-0.193***	-0.149***	-0.190***	-0.033	-0.142
	(0.049)	(0.052)	(0.042)	(0.044)	(0.232)	(0.273)
W Income tax revenue	0.136*	0.116†	0.160***	0.074	0.130	0.331
	(0.053)	(0.061)	(0.048)	(0.052)	(0.282)	(0.349)
Controls	No	Yes	No	Yes	No	Yes
R^2	0.002	0.023	0.004	0.041	0.000	0.031
Adj. R^2	0.001	0.020	0.003	0.036	-0.002	0.015
Num. obs.	4455	4455	3486	3486	969	969

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$, $^{\dagger}p < 0.1$. Standardized coeffcients. Standard errors in parentheses. W is the spatially lagged coefficient. Controls: % aged 18 or younger, % aged 65 or above, population density, population density^2, % of foreigners, trade tax revenue per capita, trade tax revenue per capita^2 (all additionally included as spatial lag).

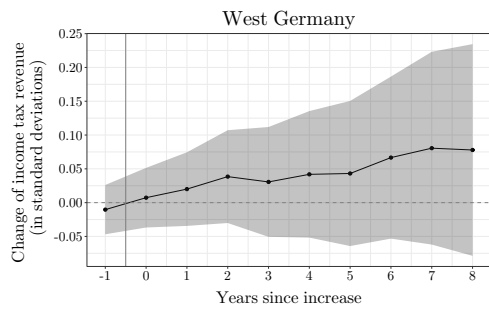**Table S6.8.** Fixed effects individual slopes (FEIS) estimator. Dep. var.: Toxicity-weighted air pollution

	Overall	West	East
	(1)	(2)	(3)
Income tax revenue$_{t-1}$	−0.006	−0.007	−0.007
	(0.041)	(0.046)	(0.079)
W Income tax revenue$_{t-1}$	0.010	−0.017	0.218
	(0.036)	(0.034)	(0.180)
Controls	Yes	Yes	Yes
R^2	0.002	0.004	0.003
Adj. R^2	0.002	0.003	0.001
Num. obs.	40095	31374	8721
Num. groups: id	4455	3486	969

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, $^{\dagger}p < 0.1$. Standardized coefficients. Cluster robust standard errors in parentheses. W is the spatially lagged coefficient. Controls: % aged 18 or younger, % aged 65 or above, population density, population density^2, % of foreigners, year dummies (except year, all additionally included as spatial lag). Slopes for FEIS: trade tax revenue per capita, trade tax revenue per capita^2.
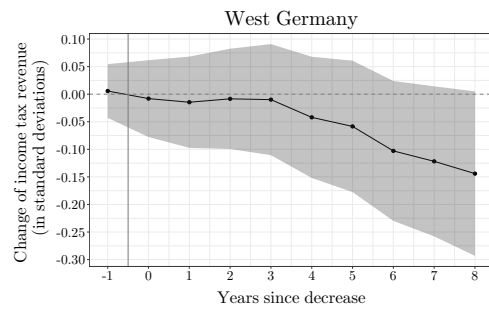
Table S6.9. Fixed effects individual slopes (FEIS) estimator Dep. var.: Income tax revenue

	Overall	West	East	Overall	West	East
	(1)	(2)	(3)	(4)	(5)	(6)
Tox air pollution$_{t-1}$	0.000	−0.000	0.000			
	(0.002)	(0.004)	(0.001)			
W Tox air pollution$_{t-1}$	0.003	0.000	0.003			
	(0.005)	(0.011)	(0.004)			
Relative rank$_{t-1}$				0.008	0.009	0.009
				(0.008)	(0.009)	(0.014)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.736	0.716	0.941	0.729	0.710	0.933
Adj. R^2	0.736	0.716	0.941	0.728	0.710	0.933
Num. obs.	40095	31374	8721	40095	31374	8721
Num. groups: id	4455	3486	969	4455	3486	969

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, $^{\dagger}p < 0.1$. Standardized coefficients. Cluster robust standard errors in parentheses. W is the spatially lagged coefficient. Controls: % aged 18 or younger, % aged 65 or above, population density, population density^2, % of foreigners, year dummies (except year, all additionally included as spatial lag in models 1 - 3). Slopes for FEIS: trade tax revenue per capita, trade tax revenue per capita^2.

(a) Increase

(b) Decrease

Figure S6.12. Effect estimates of dichotomous shocks ($\geq |1SD|$) and time paths in West Germany based on FEIS SLX estimate with cluster robust 95% confidence intervals.
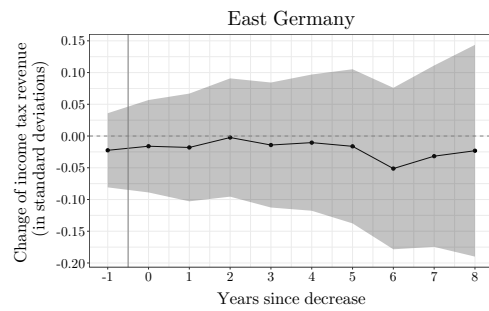
(a) Increase

(b) Decrease

Figure S6.13. Effect estimates of dichotomous shocks ($\geq |1SD|$) and time paths in East Germany based on FEIS SLX estimate with cluster robust 95% confidence intervals.

(a) Increase (b) Decrease

Figure S6.14. Effect estimates of rank reordering ($\geq |1|$ rank) and time paths in West Germany based on FEIS estimate with cluster robust 95% confidence intervals.
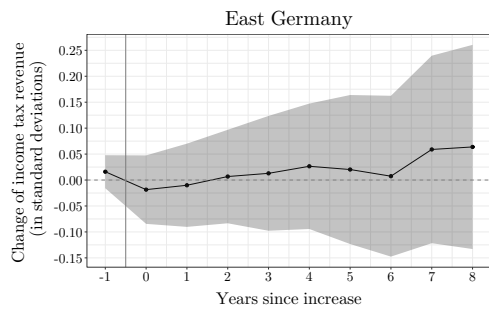

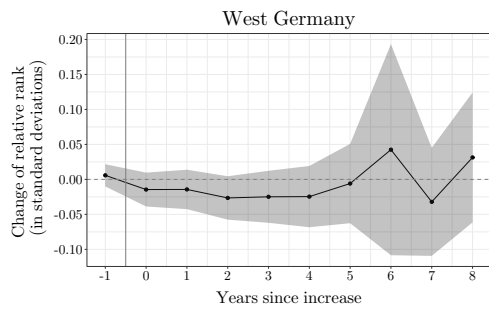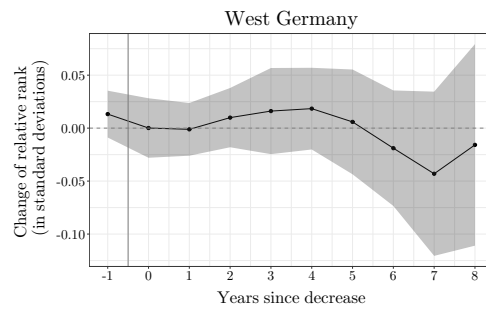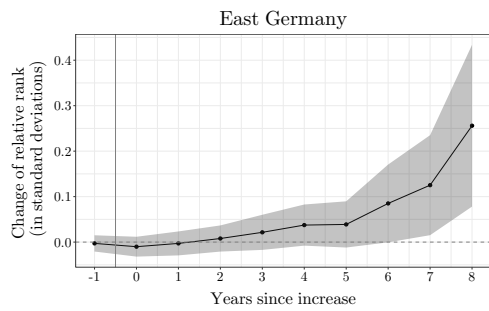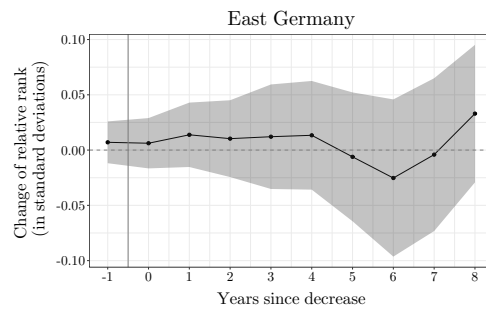(a) Increase (b) Decrease

Figure S6.15. Effect estimates of rank reordering ($\geq |1|$ rank) and time paths in East Germany based on FEIS estimate with cluster robust 95% confidence intervals.

Supplement S7. Main results including controls

Table S7.10. SLX between estimator. Dep. var.: Number of industrial facilities

	Overall		West		East	
	(1)	(2)	(3)	(4)	(5)	(6)
Income tax revenue	-0.409^{***}	-0.175^{***}	-0.439^{***}	-0.224^{***}	-0.080	0.024
	(0.052)	(0.044)	(0.054)	(0.046)	(0.172)	(0.138)
W Income tax revenue	0.440^{***}	-0.101^{*}	0.466^{***}	$-0.089^{\dagger}$	0.712^{***}	-0.010
	(0.056)	(0.051)	(0.061)	(0.054)	(0.209)	(0.177)
Share foreigners (proxy)		0.219^{***}		0.212^{***}		1.098^{***}
		(0.028)		(0.028)		(0.151)
W Share foreigners (proxy)		-0.181^{***}		-0.172^{***}		-0.412
		(0.038)		(0.039)		(0.301)
Trade tax revenue		0.240^{***}		0.217^{***}		0.702^{***}
		(0.026)		(0.028)		(0.087)
W Trade tax revenue		0.074		0.046		0.021
		(0.060)		(0.064)		(0.194)
Trade tax revenue^2		-0.008^{***}		-0.007^{***}		-0.063^{***}
		(0.001)		(0.001)		(0.010)
W Trade tax revenue^2		-0.003		-0.002		0.027
		(0.003)		(0.003)		(0.023)
Share 65 and older		-0.215^{***}		-0.276^{***}		-0.131^{**}
		(0.024)		(0.027)		(0.049)
W Share 65 and older		0.150^{***}		0.255^{***}		0.024
		(0.035)		(0.041)		(0.070)
Share 18 and younger		-0.217^{***}		-0.246^{***}		-0.232^{***}
		(0.030)		(0.033)		(0.070)
W Share 18 and younger		0.225^{***}		0.283^{***}		0.043
		(0.040)		(0.047)		(0.094)
Population density		0.326^{***}		0.321^{***}		$0.120^{\dagger}$
		(0.031)		(0.035)		(0.068)
W Population density		0.115^{**}		0.159^{***}		0.309^{**}
		(0.044)		(0.048)		(0.117)
Population density^2		0.063^{***}		0.044^{***}		0.168^{***}
		(0.005)		(0.005)		(0.011)
W Population density^2		-0.058^{***}		-0.053^{***}		-0.104^{***}
		(0.006)		(0.007)		(0.016)
R^2	0.014	0.384	0.019	0.387	0.025	0.558
Adj. R^2	0.014	0.382	0.019	0.384	0.023	0.550
Num. obs.	4455	4455	3486	3486	969	969

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, $^{\dagger}p < 0.1$. Standardized coeffcients. Standard errors in parentheses. W is the spatially lagged coefficient.

Table S7.11. Fixed effects individual slopes (FEIS) estimator. Dep. var.: Number of industrial facilities

	Overall	West	East
	(1)	(2)	(3)
Income tax revenue$_{t-1}$	$-0.012^{\dagger}$	-0.009	-0.024
	(0.007)	(0.006)	(0.029)
W Income tax revenue$_{t-1}$	$0.018^{\dagger}$	0.011	0.092
	(0.009)	(0.009)	(0.063)
Share foreigners (proxy)	$0.003^{\dagger}$	0.001	0.017
	(0.001)	(0.001)	(0.011)
W Share foreigners (proxy)	-0.000	0.000	-0.014
	(0.003)	(0.003)	(0.017)
Share 65 and older	-0.005	-0.001	$-0.022^{\dagger}$
	(0.003)	(0.003)	(0.012)
W Share 65 and older	-0.007	-0.005	-0.001
	(0.009)	(0.008)	(0.026)
Share 18 and younger	$0.005^{\dagger}$	0.002	0.015
	(0.003)	(0.003)	(0.012)
W Share 18 and younger	0.005	-0.002	0.051^{*}
	(0.004)	(0.006)	(0.026)
Population density	0.153	0.186	0.053
	(0.117)	(0.120)	(0.440)
W Population density	-0.135	-0.112	-0.323
	(0.100)	(0.091)	(0.413)
Population density^2	-0.019	-0.025	0.009
	(0.017)	(0.020)	(0.028)
W Population density^2	0.002	0.003	0.004
	(0.006)	(0.006)	(0.019)
R^2	0.015	0.015	0.028
Adj. R^2	0.015	0.014	0.026
Num. obs.	40095	31374	8721
Num. groups: id	4455	3486	969

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, $^{\dagger}p < 0.1$. Standardized coefficients. Cluster robust standard errors in parentheses. W is the spatially lagged coefficient. Controls omitted: year dummies. Slopes for FEIS: trade tax revenue per capita, trade tax revenue per capita^2.

Table S7.12. Fixed effects individual slopes (FEIS) estimator Dep. var.: Income tax revenue

	Overall	West	East	Overall	West	East
	(1)	(2)	(3)	(4)	(5)	(6)
Number facilities$_{t-1}$	-0.052^{**}	-0.080^{**}	0.006			
	(0.020)	(0.026)	(0.015)			
W Number facilities$_{t-1}$	0.047	-0.033	0.213^{***}			
	(0.044)	(0.063)	(0.046)			
Relative rank$_{t-1}$				-0.027^{*}	-0.031^{*}	-0.010
				(0.011)	(0.015)	(0.009)
Share foreigners (proxy)	-0.000	-0.002	-0.049^{***}	0.026^{***}	0.005	-0.034^{**}
	(0.009)	(0.009)	(0.011)	(0.008)	(0.009)	(0.012)
W Share foreigners (proxy)	0.084^{***}	0.047^{**}	0.066^{***}			
	(0.015)	(0.017)	(0.019)			
Share 65 and older	0.073^{***}	0.075^{***}	0.110^{***}	0.072^{***}	0.078^{***}	0.114^{***}
	(0.014)	(0.019)	(0.016)	(0.013)	(0.020)	(0.017)
W Share 65 and older	-0.038	-0.036	0.020			
	(0.025)	(0.031)	(0.028)			
Share 18 and younger	-0.045^{***}	-0.031^{*}	0.022	-0.071^{***}	-0.018	0.013
	(0.010)	(0.014)	(0.016)	(0.008)	(0.015)	(0.018)
W Share 18 and younger	-0.008	0.076^{***}	0.068^{***}			
	(0.012)	(0.020)	(0.018)			
Population density	-0.647^{***}	-0.962^{***}	0.582^{***}	0.484^{**}	-0.040	1.502^{***}
	(0.170)	(0.195)	(0.150)	(0.158)	(0.173)	(0.208)
W Population density	2.205^{***}	2.009^{***}	1.937^{***}			
	(0.290)	(0.331)	(0.336)			
Population density^2	0.042^{**}	0.062^{***}	-0.032^{**}	-0.007	$0.030^{\dagger}$	-0.070^{***}
	(0.014)	(0.015)	(0.012)	(0.016)	(0.015)	(0.016)
W Population density^2	-0.069^{*}	$-0.062^{\dagger}$	-0.049^{*}			
	(0.031)	(0.035)	(0.021)			
R^2	0.736	0.716	0.942	0.729	0.710	0.933
Adj. R^2	0.736	0.716	0.942	0.729	0.710	0.933
Num. obs.	40095	31374	8721	40095	31374	8721
Num. groups: id	4455	3486	969	4455	3486	969

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, $^{\dagger}p < 0.1$. Standardized coefficients. Cluster robust standard errors in parentheses. W is the spatially lagged coefficient. Controls omitted: year dummies. Slopes for FEIS: trade tax revenue per capita, trade tax revenue per capita^2.

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