Are Autocracies Bad for the Environment? Global Evidence from Two Centuries of Data*

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Online Appendix

A Robustness: Baseline Regressions

Table A1: Baseline regression: per-capita emission and per-capita income (recent sample)

	(1)	(2)	(3)
	CO_2 emissions (kg)	CO_2 emissions (kg)	CO_2 emissions (kg)
Per-capita income	110.4***	49.17***	69.25***
	(0.000)	(0.000)	(0.007)
Per-capita income × per-capita income	–0.138**	–0.129	–0.616
	(0.018)	(0.160)	(0.384)
Per-capita income × per-capita income × per-capita income			0.00196
			(0.470)
Constant	55.00	–76.44***	–115.2**
	(0.245)	(0.000)	(0.028)
R^2	0.614	0.894	0.896
Observations	912	912	912
Country fixed effects	No	Yes	Yes

Notes: Models estimated with per-capita carbon dioxide emissions. Per-capita income in '000 USD and per capita emission in kg. *, **, and *** denote significance at 10, 5, and 1 percent, respectively. The time period is 1950–2010.

Table A2: Baseline regression: per-capita emissions and per-capita income (log specification)

	(1) Model 1	(2) Model 2	(3) Model 3
Per-capita income	2.083***	2.181***	2.084***
	(0.000)	(0.000)	(0.000)
Per-capita income × per-capita income	–0.199***	–0.271***	–0.196*
	(0.000)	(0.000)	(0.055)
Per-capita income × per-capita income × per-capita income			–0.0142
			(0.391)
Constant	3.244***	1.511***	1.535***
	(0.000)	(0.002)	(0.001)
R^2	0.691	0.853	0.853
Observations	1,205	1,205	1,205
Country Fixed Effects	No	Yes	Yes

Notes: Models estimated with per-capita carbon dioxide emissions. Per-capita income in '000 USD and per-capita emission in kg. Both per-capita carbon dioxide emissions and per-capita income in natural logarithm. *, **, and *** denote significance at 10, 5, and 1 percent, respectively. The time period is 1790–2010.

Table A3: Baseline regression: per-capita emission and per-capita income (recent sample with log specification)

	(1) Model 1	(2) Model 2	(3) Model 3
Per-capita income	1.914***	1.424***	1.310***
	(0.000)	(0.000)	(0.000)
Per-capita income × per-capita income	–0.155***	–0.153***	–0.0669
	(0.000)	(0.000)	(0.512)
Per-capita income × per-capita income × per-capita income			–0.0154
			(0.318)
Constant	3.285***	1.927***	1.958***
	(0.000)	(0.000)	(0.000)
R^2	0.748	0.921	0.921
Observations	912	912	912
Country fixed effects	No	Yes	Yes

Notes: Models estimated with per-capita carbon dioxide emissions. Per-capita income in '000 USD and per-capita emission in kg. Both per-capita carbon dioxide emissions and per-capita income in natural logarithm. *, **, and *** denote significance at 10, 5, and 1 percent, respectively. The time period is 1950–2010.

Table A4: Baseline regression: per-capita emissions and per-capita income (recent sample with log specification)

	(1) Model 1	(2) Model 2	(3) Model 3
Per-capita income	1.889***	1.591***	1.415***
	(0.000)	(0.000)	(0.000)
Per-capita income × per-capita income	–0.142***	–0.166***	–0.0332
	(0.000)	(0.000)	(0.807)
Per-capita income × per-capita income × per-capita income			–0.0239
			(0.257)
Constant	3.383***	1.812***	1.852***
	(0.000)	(0.003)	(0.002)
R^2	0.737	0.927	0.928
Observations	664	664	664
Country Fixed Effects	No	Yes	Yes

Notes: Models estimated with per-capita carbon dioxide emissions. Per-capita income in '000 USD and per-capita emissions in kg. Both per-capita carbon dioxide emissions and per-capita income in natural logarithm. *, **, and *** denote significance at 10, 5, and 1 percent, respectively. The time period is 1950–2000.

B Threshold Regression with Country Fixed Effects

The extended EKC model excluding the trade-to-GDP ratio in the main text is given by:

$$e_{it} = \theta_i + \theta_1 y_{it} + \theta_2 y_{it}^2 + \theta_3 I_{it} + \theta_4 I_{it} \times y_{ti} + \theta_5 p_{it} + \theta_6 p_{it}^2 + \epsilon_{it} \tag{A1}$$

From equation (A1) we can see that $\frac{de_{it}}{dy_{it}} = \theta_1 + 2 \times \theta_2 y_{it} + \theta_4 I_{it}$ and the marginal emission intensity depends on income and institutions. Equation (A1) can be rewritten as:

$$e_{it} = \theta_i + (\theta_1 + \theta_4 I_{it} \times) y_{it} + \theta_2 y_{it}^2 + \theta_3 I_{it} + \theta_5 p_{it} + \theta_6 p_{it}^2 + \epsilon_{it} \tag{A2}$$

$$e_{it} = \theta_i + (\theta (I_{it})) y_{it} + \theta_2 y_{it}^2 + \theta_3 I_{it} + \theta_5 p_{it} + \theta_6 p_{it}^2 + \epsilon_{it} \tag{A3}$$

In equation (A3) we have assumed that the coefficient associated with y_{it} is a function of I_{it} or depends on I_{it}. The marginal emission intensity from equation (11) also depends

on the income and institution. The above model can be estimated using a threshold regression framework:

$$e_{it} = \theta_i + \theta_{4,1} y_{ti} \left((I_{it}) < \gamma \right) + \theta_{4,2} y_{ti} \left((I_{it}) \geq \gamma \right) + \theta_2 y_{it}^2 + \theta_3 I_{it} + \theta_5 p_{it} + \theta_6 p_{it}^2 + \epsilon_{it} \quad \text{(A4)}$$

where $\theta_{4,1}$ and $\theta_{4,2}$ are coefficients associated with y_{it} in two regimes based on I_{it}. Since the coefficient associated with y_{it} varies in two regimes, the turning point also varies in two regimes.[1]

$$\text{Turning point in regime (1)} = \frac{-\theta_{4,1}}{2\theta_2}$$

$$\text{Turning point in regime (2)} = \frac{-\theta_{4,2}}{2\theta_2}$$

We estimate equation (A4) with the demeaned variable as explained above, and the results are given in Table A5. The Stata command used to estimate the threshold model is for cross-sectional regression. Therefore we do fixed effect transformation (demean the country-level variables) before estimation. Model 1 allows for the coefficient of y_{it} as well as the intercept to vary across regimes identified by the ADI. Other coefficients, such as of y_{it}^2, p_{it}, p_{it}^2, and I_{it}, remain constant across the two regimes. The estimated threshold for the ADI is 1.2 in model 1. As we can see, for ADI $<$ 1.2 the coefficient associated with y_{it} is 82.29; beyond that this coefficient declines to 62.23. The turning points in the two regimes are also different. With ADI $>$ 1.2, the turning point is USD40,000 less than in countries having ADI $<$ 1.2. Since the intercept in regime 2 is not significant in model 1, we estimate another model without the intercept; that model gives similar results and slightly higher value for threshold ADI.

The above threshold regression suggests that institutions affect marginal emission intensity significantly. These results also suggest that there is a significant threshold value of institutions beyond which the impact of institutions on the turning point becomes significant.

[1]We estimate the model using the Stata command "threshold," which is based on Gonzalo and Pitarakis (2002) with one threshold. As this command is for cross-sectional regressions we do fixed effect transformation (demean the country-level variables) before estimation.

Table A5: Estimation of marginal emission intensity with the ADI: threshold regression

Variable	Model 1	Model 2
Per-capita income × per-capita Income	-0.25^{***}	-0.25^{***}
Population density	2.896^{***}	2.749^{***}
Population density × Population density	-0.0003^{***}	-0.0003^{***}
ADI	18.87^{**}	18.87^{**}
Per-capita income regime (1)	82.29^{***}	82.32^{***}
Constant regime (1)	157.43^{***}	
Per-capita income regime (2)	62.23^{***}	65.90^{***}
Constant regime (2)	32.04	
Threshold ADI	1.2	2.5
Turning point regime (1)	164.5	164.6
Turning point regime (2)	124.6	131.8
Observations	664	664

Notes: Estimates obtained from $e_{it} = \theta_0 + \theta_{4,1} y_{ti} \left((I_{it}) < \gamma\right) + \theta_{4,2} y_{ti} \left((I_{it}) \geq \gamma\right) + \theta_2 y_{it}^2 + \theta_3 I_{it} + \theta_5 p_{it} + \theta_6 p_{it}^2 + \epsilon_{it}$. Models are estimated with per-capita carbon dioxide emissions in kg. Per-capita income is in '000 USD. The ADI is represented by *Polity 2*. popden is population density. *, **, and *** denote significance at 10, 5, and 1 percent, respectively. Regime (2) is beyond the ADI score mentioned as the threshold ADI score. The time period is 1950–2000.

C Further Robustness: Additional Democracy Variables

In this section we provide further evidence of the impact of institutions on the turning point. We use three dichotomous regime classifications (0 for autocracy, 1 for democracy). The first one is from Cheibub et al. (2010) and the second is from Boix et al. (2013). We call them CGV and BMR, respectively. The third measure is from Acemoglu et al. (2019). Acemoglu et al. (2019) use data from Freedom House, Polity IV, CGV, and BMR to construct their dichotomous regime. This is represented as ANRR. Details about the construction of the ANRR democracy index are given in Acemoglu et al. (2019). These three additional measures of democracy index are available for 1960–2010. Therefore, our regressions are with fewer observations. Regression results are given in Table A6. Evidence in favor of the EKC hypothesis continues to hold. The interaction of

the democracy index with per-capita income has the expected sign, as argued in Section 2. Model 4 gives the estimates obtained with the ANRR index after dropping countries that transition to and from democracy.

Table A6: Effect of institutions using additional democracy indices

	(1) Model 1	(2) Model 2	(3) Model 3	(4) Model 4
Per-capita income	126.4***	121.3***	123.3***	122.9***
	(0.001)	(0.002)	(0.001)	(0.002)
Per-capita income in × per-capita income	–0.412**	–0.392**	–0.400**	–0.398**
	(0.012)	(0.017)	(0.015)	(0.019)
popden	3.482***	3.304**	3.403***	3.494**
	(0.006)	(0.012)	(0.009)	(0.016)
popden × popden	–0.00147	–0.00130	–0.00140	–0.00148
	(0.160)	(0.212)	(0.177)	(0.192)
Democracy measure by BMR	423.4***			
	(0.006)			
Democracy measure by BMR × per-capita income	–84.93**			
	(0.010)			
Democracy measure by CGV		387.6***		
		(0.009)		
Democracy measure by CGV × per-capita income		–79.94**		
		(0.016)		
Democracy measure by ANRR			369.7**	
			(0.013)	
Democracy measure by ANRR × per-capita income			–81.71**	
			(0.014)	
Democracy measure by ANRR				431.7***
				(0.009)
Democracy measure by ANRR × per-capita income				–81.81**
				(0.018)
Constant	–305.7***	–291.5***	–297.7***	–299.0***
	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.923	0.922	0.922	0.921
Observations	588	586	588	511
Country fixed effects	Yes	Yes	Yes	Yes

Notes: popden is population density. Models estimated with per-capita carbon dioxide emissions. Per-capita income is in '000 USD and per-capita emissions in kg. CGV is the democracy index from Cheibub et al. (2010) and the BMR is the democracy index from Boix et al. (2013). ANRR is the democracy index from Acemoglu et al. (2019). Acemoglu et al. (2019) use data from Freedom House, Polity IV, CGV, and BMR to construct their dichotomous regime. Details about the construction of the ANRR democracy index are given in Acemoglu et al. (2019). Models 3 and 4 both use the ANRR measure of institutions. Model 4 is estimated with countries having always autocracy or democracy. In other words, we drop those countries that transition from autocracy to democracy and democracy to autocracy. The number of observations varies as different explanatory variables are available for different time periods. The time period is 1960–2000.

As we can see from Table A7, these democracy indices give similar turning points. The turning point in autocracies is roughly three times the turning point in democracies. This result holds even after dropping countries that transition to and from democracy. Figures A1–A4 show these turning points graphically.

Table A7: Turning point estimates: other democracy indices

Variable	Coefficient	Coefficient	Coefficient	Coefficient	Turning point democracy	Turning point autocracy
Per-capita income	126.4***	121.3***	123.3***	122.9***		
Per-capita income × per-capita income	–0.412**	–0.392**	–0.40**	–0.398**		
BMR × per-capita income	–84.93**				50	153
CGV × per-capita income		–79.94**			53	155
ANRR × per-capita income			–81.71**		52	154
ANRR × per-capita income $^{+}$				–81.71**	52	154

Notes: *, **, and *** denote significance at 10, 5, and 1 per cent, respectively. Turning points are in '000 USD at current prices. Turning points for autocracy and democracy are obtained by using the value of the respective index 0 and 1. + denotes the turning point obtained with the ANRR index after dropping countries that transition to and from democracy. The time period is 1960–2000.

Figure A1: Turning point from $e_{it} = \theta_0 + \theta_1 y_{it} + \theta_2 y_{it}^2 + \theta_3 l_{it} + \theta_4 l_{it} \times y_{ti} + \theta_5 p_{it} + \theta_6 p_{it}^2 + \epsilon_{it}$. l_{it} is the BMR index of democracy from Boix et al. (2013). Lines represent marginal emission intensity or change in per-capita emissions for a unit change in per-capita income. The intersection with the x-axis gives the income level of the turning point, which is equal to $\left(\frac{-\theta_1}{2\theta_2}\right)$ for category 0 (BMR = 0, autocracy). For democracy (BMR = 1) the turning point is given by $\frac{-\theta_1-\theta_4}{2\theta_2}$. Turning points are in '000 USD at current prices. The time period is 1960–2000.

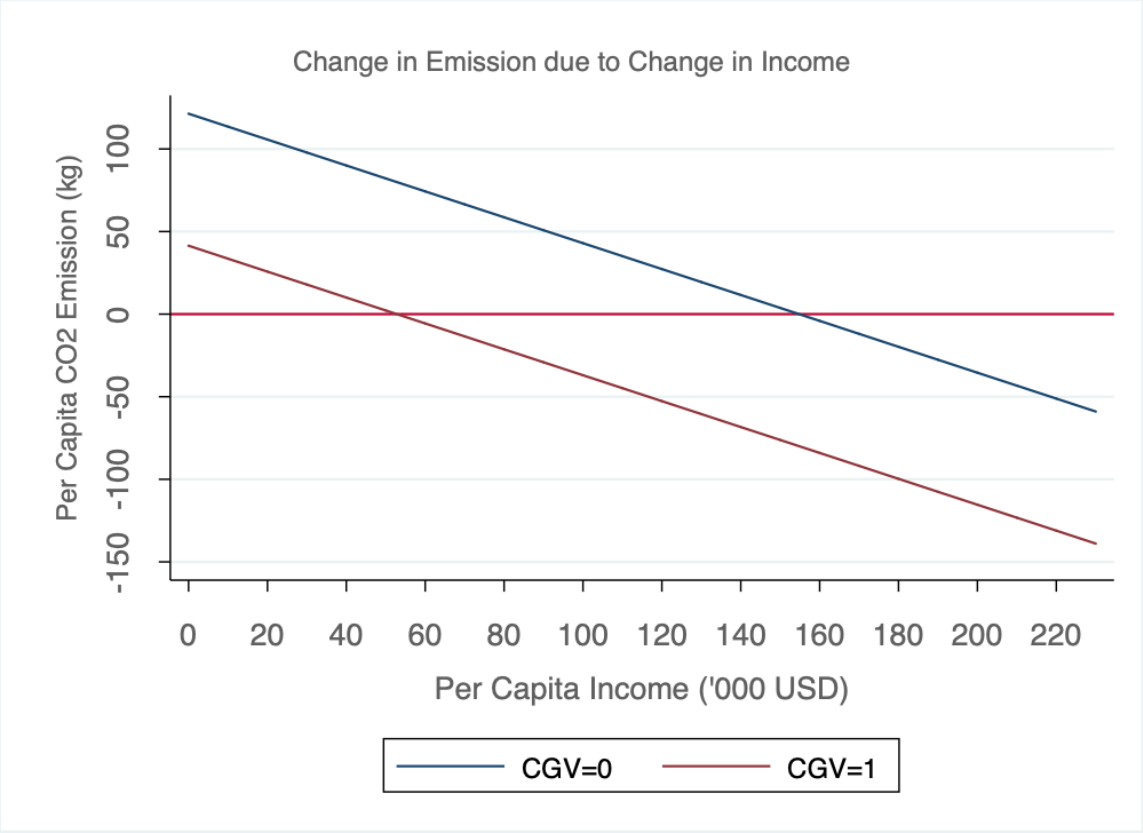

Figure A2: Turning point from $e_{it} = \theta_0 + \theta_1 y_{it} + \theta_2 y_{it}^2 + \theta_3 l_{it} + \theta_4 l_{it} \times y_{ti} + \theta_5 p_{it} + \theta_6 p_{it}^2 + \epsilon_{it}$. l_{it} is the CGV index of democracy from Cheibub et al. (2010). Lines represent the marginal emission intensity or change in per-capita emissions for a unit change in per-capita income. The intersection with the x-axis gives the income level of the turning point, which is equal to $\left(\frac{-\theta_1}{2\theta_2}\right)$ for category 0 (CGV = 0, autocracy). For democracy (CGV = 1) the turning point is given by $\frac{-\theta_1-\theta_4}{2\theta_2}$. Turning points are in '000 USD at current prices. The time period is 1960–2000.

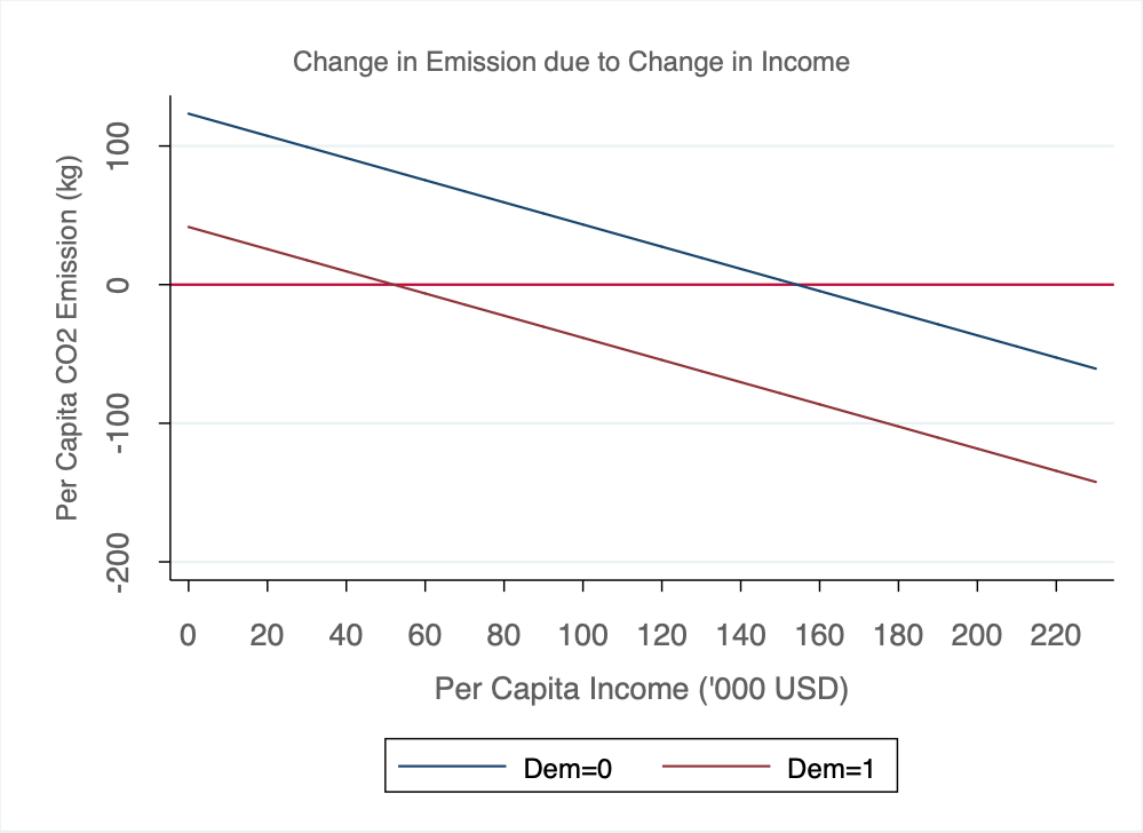

Figure A3: Turning point from $e_{it} = \theta_0 + \theta_1 y_{it} + \theta_2 y_{it}^2 + \theta_3 I_{it} + \theta_4 I_{it} \times y_{ti} + \theta_5 p_{it} + \theta_6 p_{it}^2 + \epsilon_{it}$. I_{it} is the ANRR index of democracy from Acemoglu et al. (2019). Lines represent the marginal emission intensity or change in per-capita emissions for a unit change in per-capita income. The intersection with the x-axis gives the income level of the turning point, which is equal to $\left(\frac{-\theta_1}{2\theta_2}\right)$ for category 0 (Dem = 0, autocracy). For democracy (Dem = 1) the turning point is given by $\frac{-\theta_1-\theta_4}{2\theta_2}$. Turning points are in '000 USD at current prices. The time period is 1960–2000.

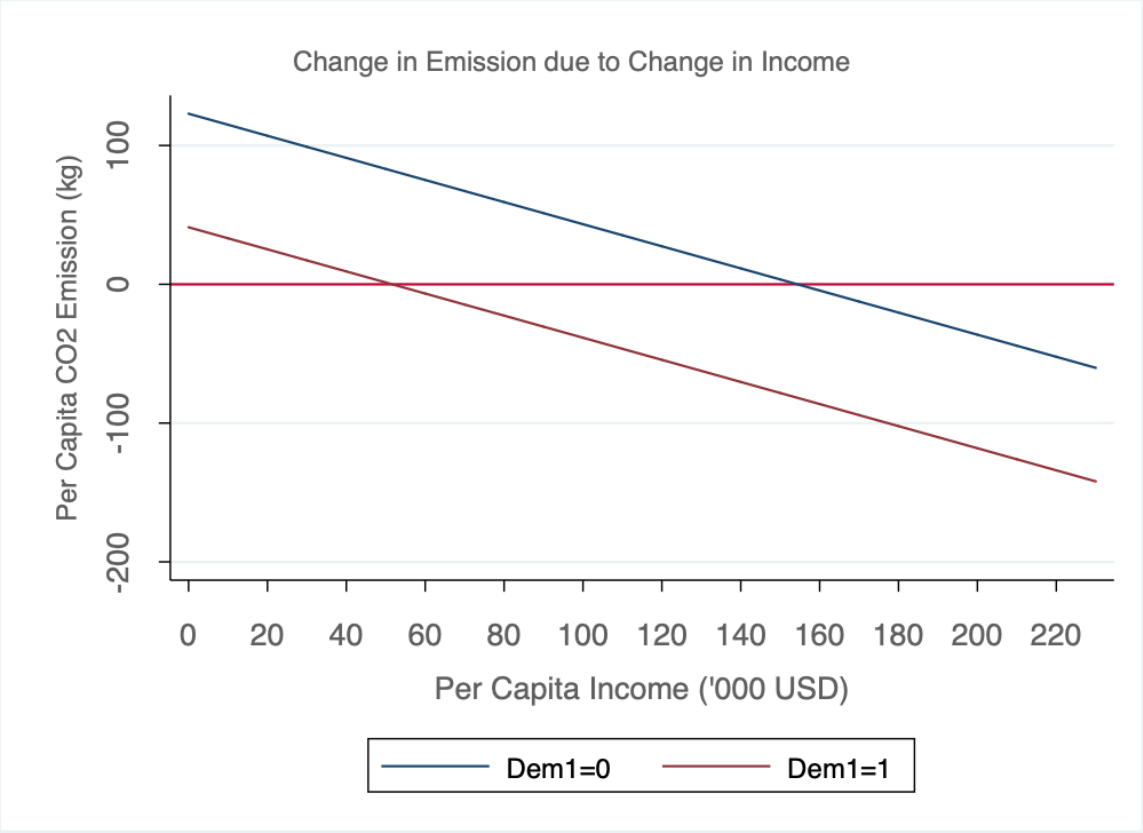

Figure A4: Turning point from $e_{it} = \theta_0 + \theta_1 y_{it} + \theta_2 y_{it}^2 + \theta_3 I_{it} + \theta_4 I_{it} \times y_{ti} + \theta_5 p_{it} + \theta_6 p_{it}^2 + \epsilon_{it}$. I_{it} is the ANRR index of democracy from Acemoglu et al. (2019). Lines represent the marginal emission intensity or change in per-capita emission for a unit change in per-capita income. The intersection with the x-axis gives the income level of the turning point, which is equal to $\left(\frac{-\theta_1}{2\theta_2}\right)$ for category 0 (Dem1 = 0, autocracy). For democracy (Dem1 = 1) the turning point is given by $\frac{-\theta_1-\theta_4}{2\theta_2}$. Countries that transition to and from democracy are dropped. Turning points are in '000 USD at current prices. The time period is 1960–2000.

Figure A5: θ_d from $e_{it} = \theta_0 + \theta_1 y_{it} + \theta_2 y_{it}^2 + \theta_3 I_{it} + \sum_d \theta_d (I_{it} \times y_{it} \times D_d) + \epsilon_{it}$. D_d is a dummy variable for each decade. I_{it} is the BMR index of democracy from Boix et al. (2013). The dots represent the difference in marginal emission intensity between democracies and autocracies for a given decade. The vertical bars denote 90 percent confidence bands for the same. The BMR data is available until 2000 only.

Figure A6: θ_d from $e_{it} = \theta_0 + \theta_1 y_{it} + \theta_2 y_{it}^2 + \theta_3 I_{it} + \sum_d \theta_d (I_{it} \times y_{it} \times D_d) + \epsilon_{it}$. D_d is a dummy variable for each decade. I_{it} is the CGV index of democracy from Cheibub et al. (2010). The dots represent the difference in marginal emission intensity between democracies and autocracies for a given decade. The vertical bars denote 90 percent confidence bands for the same. The CGV data is available until 2000 only.

Figure A7: θ_d from $e_{it} = \theta_0 + \theta_1 y_{it} + \theta_2 y_{it}^2 + \theta_3 I_{it} + \sum_d \theta_d (I_{it} \times y_{it} \times D_d) + \epsilon_{it}$. D_d is a dummy variable for each decade. I_{it} is the ANRR index of democracy from Acemoglu et al. (2019). The dots represent the difference in marginal emission intensity between democracies and autocracies for a given decade. The vertical bars denote 90 percent confidence bands for the same.

D Turning Points for the ADI and Regimes of the World Categories

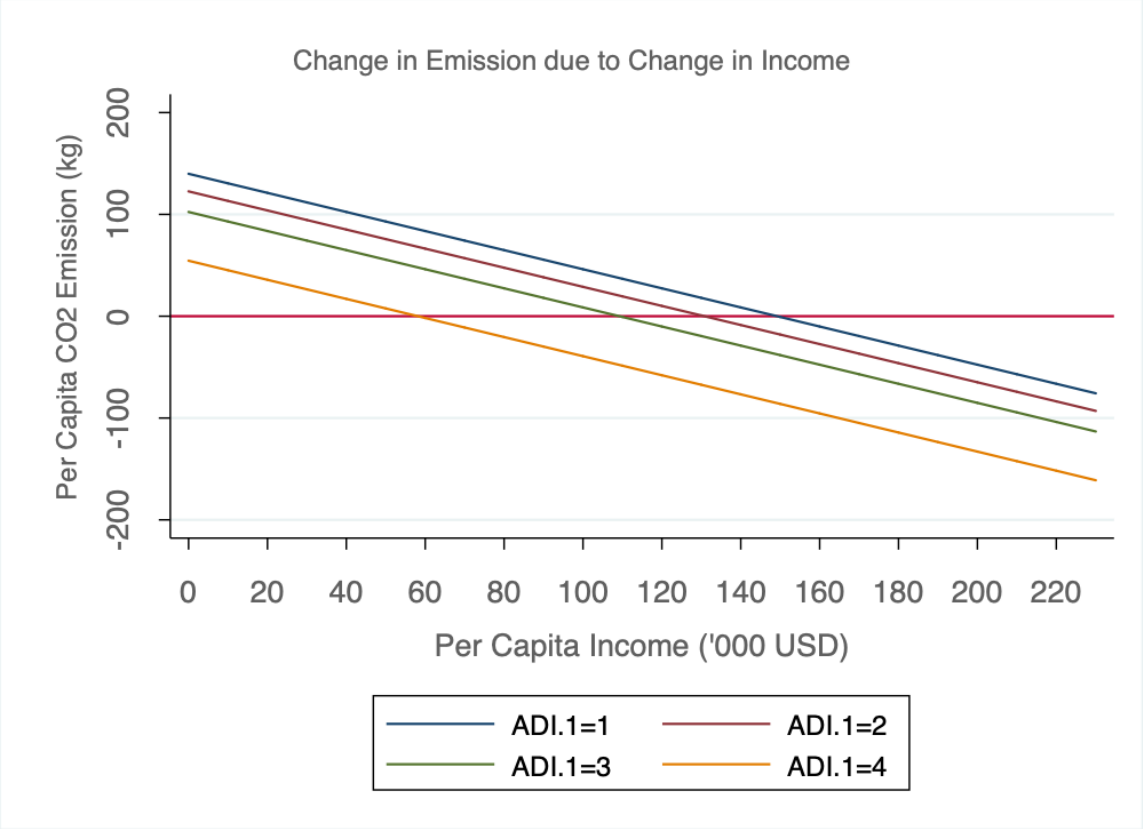

Figure A8: Turning point from $e_{it} = \theta_0 + \theta_1 y_{it} + \theta_2 y_{it}^2 + \theta_3 l_{it} + \sum_{j=2}^{4} \theta_{4j} l_{j,it} \times y_{ti} + \theta_5 p_{it} + \theta_6 p_{it}^2 + \epsilon_{it}$. $l_{j,it}$ are four categories created from 21 categories of *Polity 2*. The ADI is representing *Polity 2*. ADI.1 = 1 for ADI index ≥ -10 and ≤ -5, ADI.1 = 2 for ADI > -5 and ≤ 0, ADI.1 = 3 for ADI > 0 and ≤ 5 and ADI.1 = 4 for ADI > 5 and ≤ 10. Lines represent the marginal emission intensity or change in per-capita emission for a unit change in per-capita income. The intersection with the x-axis gives the income level of the turning point, which is equal to $\left(\frac{-\theta_1}{2\theta_2}\right)$ for category 1, given by ADI.1 = 1. For category $j = 2, 3, 4$ the turning points are given by $\frac{-\theta_1 - \theta_{4j} \times l_{j,it}}{2\theta_2}$, which is shown as ADI.1 = 2, ADI.1 = 3, and ADI.1 = 4, respectively. Turning points are in '000 USD at current prices. the time period is 1950–2000.

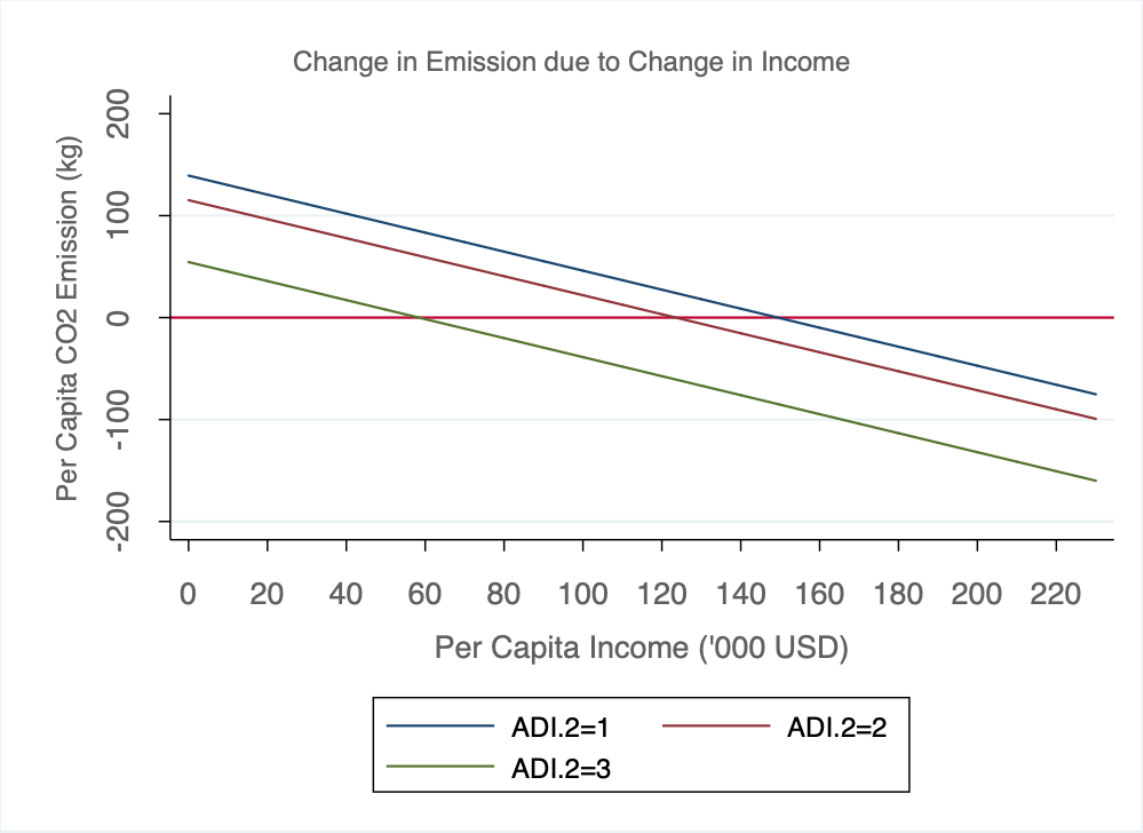

Figure A9: Turning point from $e_{it} = \theta_0 + \theta_1 y_{it} + \theta_2 y_{it}^2 + \theta_3 I_{it} + \sum_{j=2}^{3} \theta_{4j} I_{j,it} \times y_{ti} + \theta_5 p_{it} + \theta_6 p_{it}^2 + \epsilon_{it}$. $I_{j,it}$ are three categories created from 21 categories of *Polity 2*. The ADI is representing *Polity 2*. ADI.2 = 1 for ADI ≤ -5, ADI.2 = 2 for ADI > -5 and ≤ 5, and ADI.2 = 3 for ADI > 5. Lines represent the marginal emission intensity or change in per-capita emissions for a unit change in per-capita income. The intersection with the x-axis gives the income level of the turning point, which is equal to $\left(\frac{-\theta_1}{2\theta_2}\right)$ for category 1 (ADI.2 = 1). For category $j = 2, 3$ the turning points are given by $\frac{-\theta_1 - \theta_{4j} \times I_{j,it}}{2\theta_2}$, which is shown as ADI.2 = 2, ADI.2 = 3, respectively. Turning points are '000 USD at current prices. The time period is 1950–2000.

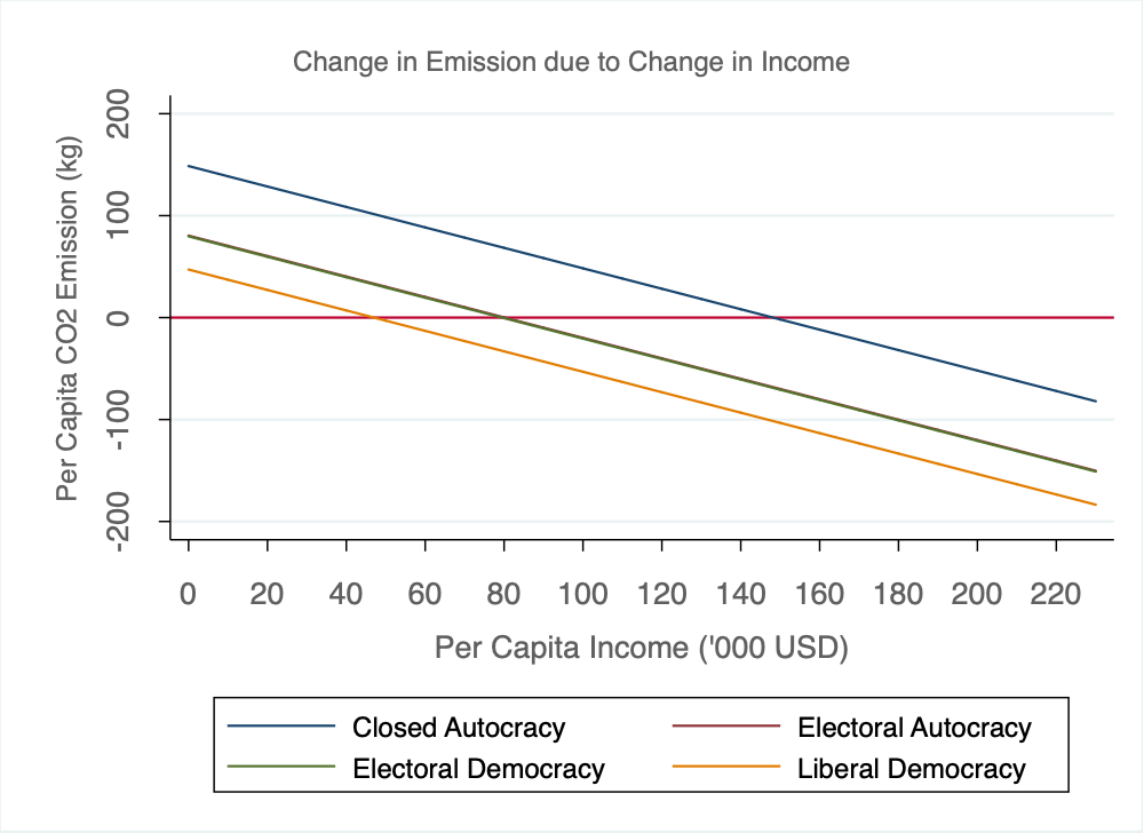

Figure A10: Turning point from $e_{it} = \theta_0 + \theta_1 y_{it} + \theta_2 y_{it}^2 + \theta_3 l_{it} + \sum_{j=1}^{3} \theta_{4j} l_{j,it} \times y_{ti} + \theta_5 p_{it} + \theta_6 p_{it}^2 + \epsilon_{it}$. $l_{j,it}$ is data from Regimes of the World, which is a categorical variable. 0, closed autocracy; 1, electoral autocracy; 2, electoral democracy; 3, liberal democracy. Lines represent the marginal emission intensity or change in per-capita emissions for a unit change in per-capita income. The intersection with the x-axis gives the income level of the turning point, which is equal to $\left(\frac{-\theta_1}{2\theta_2}\right)$ for category 0 (closed autocracy). For category $j = 1, 2, 3$ the turning points are given by $\frac{-\theta_1 - \theta_{4j} \times l_{j,it}}{2\theta_2}$. Turning points are in '000 USD at current prices. The time period is 1950–2000.

E Robustness Extended EKC Regressions with ADI Categories

Table A8: Marginal emission intensity and ADI category: log specification

	(1) CO_2 emissions (kg)	(2) CO_2 emissions (kg)
Per-capita income	1.495***	1.265***
	(0.000)	(0.000)
Per-capita income × per-capita income	–0.126***	–0.143***
	(0.001)	(0.000)
popden	0.00336***	0.00189***
	(0.000)	(0.000)
popden × popden	–0.000000333***	–0.000000185***
	(0.000)	(0.000)
ADI.1 = 2	0.260*	0.117
	(0.081)	(0.415)
ADI.1 = 3	–0.0475	–0.153
	(0.801)	(0.375)
ADI.1 = 4	0.410***	0.230*
	(0.002)	(0.097)
ADI.1 = 2 × per-capita income	–0.188*	–0.132
	(0.095)	(0.248)
ADI.1 = 3 × per-capita income	–0.0778	–0.0597
	(0.589)	(0.655)
ADI.1 = 4 × per-capita income	–0.242**	–0.260***
	(0.011)	(0.008)
Constant	1.776***	1.315***
	(0.003)	(0.007)
R^2	0.933	0.939
Observations	664	664
Country fixed effects	Yes	Yes
Time trend	No	Yes

Notes: popden is population density. Models are estimated with per-capita carbon dioxide emissions. Per-capita income is in '000 USD and per-capita emissions are in kg. Both per-capita carbon dioxide emissions and per-capita income are with natural logarithm. The ADI is represented by *Polity 2*. ADI.1 = 1 for ADI index ≥ -10 and ≤ -5, ADI.1 = 2 for ADI > -5 and ≤ 0, ADI.1 = 3 for ADI > 0 and ≤ 5, and ADI.1 = 4 for ADI > 5 and ≤ 10. ADI.1 = 1 is the base group for comparison. *, **, and *** denotes significance at 10, 5, and 1 percent, respectively. The time period is 1950–2000.

F Carbon Emissions

F.1 Production-Based Emissions

The main reference for calculation of carbon dioxide emissions for 1950 onward is Marland and Rotty (1984) and Boden et al. (1995, 2009). Before 1950 the estimates are based on Andres et al. (1999), which follows Marland and Rotty (1984) and Boden et al. (1995). The carbon dioxide emissions are calculated for each fuel type using the formula

$$CO_{2i} = P_i \times FO_i \times C_i$$

where i is type of fuel, P is amount produced, FO is fraction oxidized, and C is the average carbon content. Since all fuel types have different compositions and varying energy content, the fuel production data is converted into energy or energy equivalents. Also, there are inefficiencies in combustion and non-fuel use, which varies across fuel types and must be taken into account to obtain FO. The final component C is related to the heating value of different types of fuel. Marland and Rotty (1984) arrive at the following C_i

- From natural gas production: carbon content in 10^6 tons per thousand 10^{12} joules = $0.0137 \pm 2\%$
- From crude oil and natural gas liquid production: carbon content in tons C per ton crude oil = $0.85 \pm 1\%$
- From coal production: carbon content in tons C per ton coal equivalent = $0.746 \pm 2\%$
- From natural gas flaring: carbon content in tons per thousand m^3 = $0.525 \pm 3\%$
- From cement production: carbon content in metric tons per metric ton cement = 0.136

This suggests that the carbon content of fuel types has not changed over time the but components of FO have, Andres et al. (1999).

F.2 Consumption-Based Emissions

The consumption-based emissions are based on Peters (2008) and Peters et al. (2011, 2012). These are calculated in two steps. First, the territory-based emissions are converted to production-based emissions consistent with the System of National Accounts (SNA). This is an extension of the SNA and is also known as the National Accounting Matrix including Environmental Accounts (Pedersen and de Haan, 2006). In the second step, the production-based emissions are reallocated to consumption-based emissions using detailed input-output tables. Once we have production- and consumption-based emissions, it is straightforward to obtain the trade-related emissions.

Since the same production-based emissions are used to construct consumption-based emissions, it is clear that carbon coefficients have not changed over time, Andres et al. (1999).

References

Acemoglu, D., S. Naidu, P. Restrepo, and J.A. Robinson (2019). "Democracy Does Cause Growth." *Journal of Political Economy*, 127(1): 47–100.

Andres, R.J., D.J. Fielding, G. Marland, T.A. Boden, N. Kumar, and A.T. Kearney (1999). "Carbon Dioxide Emissions from Fossil-Fuel Use, 1751–1950." *Tellus B*, 51(4): 759–765.

Boden, T., G. Marland, and R. Andres (1995). "Estimates of Global, Regional and National Annual CO2 Emissions from Fossil-Fuel Burning, Hydraulic Cement Production and Gas-Flaring: 1950–1992." Technical Report. Oak Ridge, TN: Oak Ridge National Laboratory.

Boden, T.A., G. Marland, and R.J. Andres (2009). "Global, Regional, and National Fossil-Fuel CO2 Emissions." Technical Report. Oak Ridge, TN: Oak Ridge National Laboratory.

Boix, C., M. Miller, and S. Rosato (2013). "A Complete Data Set of Political Regimes, 1800–2007." *Comparative Political Studies*, 46(12): 1523–1554.

Cheibub, J.A., J. Gandhi, and J.R. Vreeland (2010). "Democracy and Dictatorship Revisited." *Public Choice*, 143(1–2): 67–101.

Marland, G. and R.M. Rotty (1984). "Carbon Dioxide Emissions from Fossil Fuels: A Procedure for Estimation and Results for 1950–1982." *Tellus B*, 36(4): 232–261.

Pedersen, O.G. and M. de Haan (2006). "The System of Environmental and Economic Accounts: 2003 and the Economic Relevance of Physical Flow Accounting." *Journal of Industrial Ecology*, 10(1–2): 19–42.

Peters, G.P. (2008). "From Production-Based to Consumption-Based National Emission Inventories." *Ecological Economics*, 65(1): 13–23.

Peters, G.P., J.C. Minx, C.L. Weber, and O. Edenhofer (2011). "Growth in Emission Transfers via International Trade from 1990 to 2008." *Proceedings of the National Academy of Sciences*, 108(21): 8903–8908.

Peters, G.P., S.J. Davis, and R. Andrew (2012). "A Synthesis of Carbon in International Trade." *Biogeosciences*, 9(8): 3247–3276.