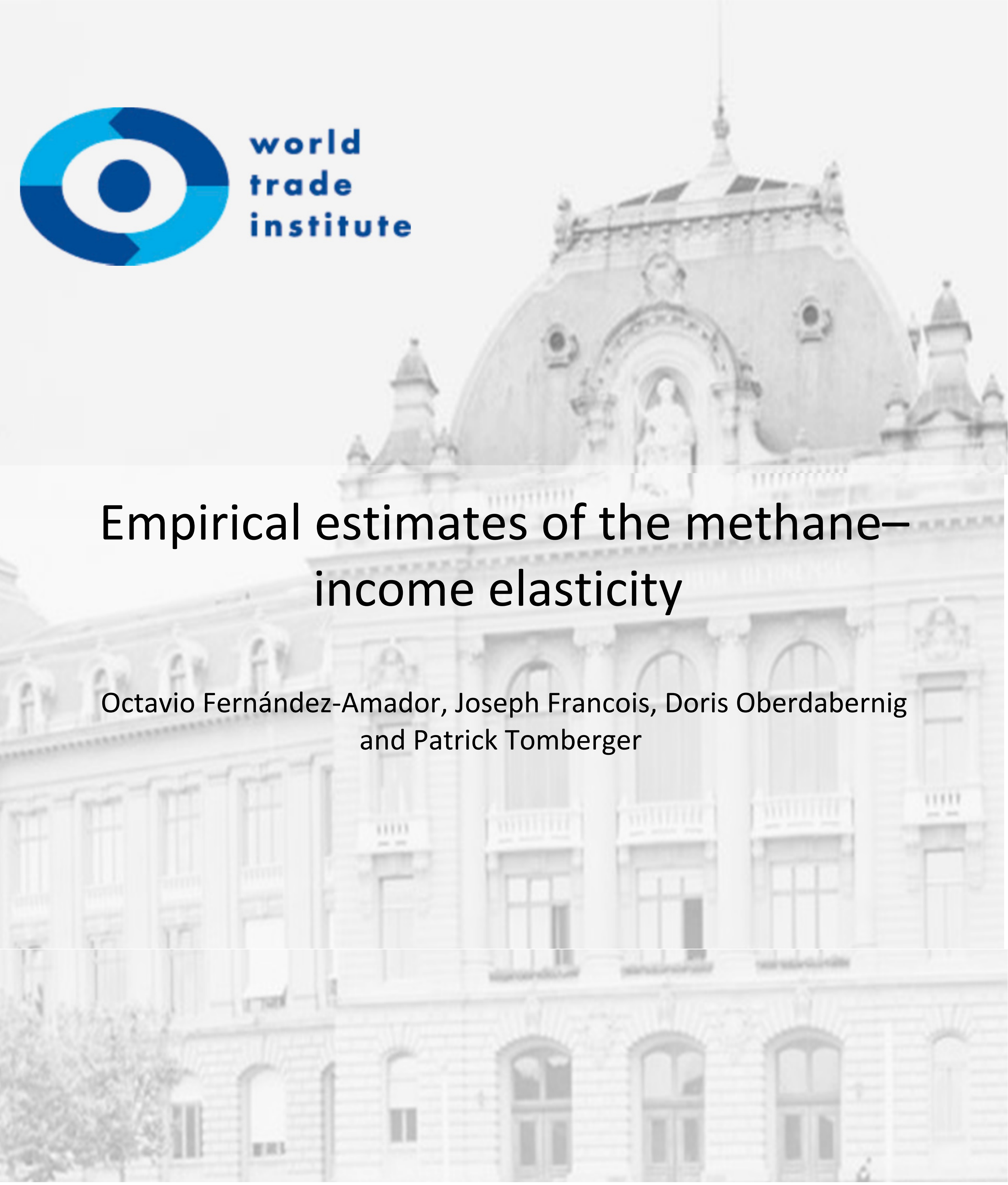

Empirical estimates of the methane–income elasticity

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Abstract

We estimate the income-elasticity of methane emissions per capita derived from production, final production, and consumption in a global sample of countries for 1997–2011. We find relative decoupling between emissions and income, and evidence for a piecewise-linear relationship. The relation between economic growth and emissions improves as countries reach high levels of income, although the magnitude of the improvement is small. This points to very minor methane-efficiency gains from economic development.

Keywords: Economic growth, methane emissions, production-based inventories, methane footprint, income-elasticity, threshold estimation.

JEL-codes: F18, F64, O44, Q54, Q56.

1 Introduction

Methane is the second largest greenhouse-gas contributor to global warming. There is evidence of a strong, mostly coincident linkage between methane emissions and global temperature trends (Estrada et al., 2013).[1] Yet, the literature analyzing the socio-economic factors driving anthropogenic methane emissions is scarce. Existing studies are cross-sectional (Burns et al., 1997, Rosa et al., 2004, Jorgenson, 2006), leaving room to omitted variable bias, or cover only a small set of countries using unbalanced panel data (Jorgenson and Birkholz, 2010). They do not account for the potential endogeneity of key variables such as economic growth, and focus only on production-based emissions. However, the link between national production and consumption patterns has been weakened by the recent trend of globalization of production chains (Baldwin and López-González, 2015).

We estimate the relationship between economic development and methane emissions embodied in production, final production, and consumption using a new dataset recently developed by Fernández-Amador et al. (2017b). We evaluate the socio-economic determinants of methane footprints using balanced global panel data covering 78 regions (comprising 178 countries) for five years from 1997–2011. We explicitly allow for non-linearities and account for potential sources of endogeneity. Because the warming potential of methane during 1997–2011 is equivalent to about 80% of that of Carbon Dioxide (CO_2) from fossil fuel combustion when computed over a 20-years period (Fernández-Amador et al., 2017b), understanding the socio-economic drivers of methane footprints is essential for guiding environmental policy.

2 Econometric model

We estimate piecewise-linear regression models in which the threshold is endogenously estimated (Hansen, 1999, Caner and Hansen, 2004) and test them against models without threshold (Hansen, 1996, 1999).[2]

The econometric model is specified as

$$E_{it} = \sum_{k=1}^{m} [I(\tau_{k-1} < q_{it} \leq \tau_k)\beta_k y_{it}] + \gamma_1 a_{it} + \gamma_2 t_{it} + Z'_{it}\delta + \nu_t + \mu_i + u_{it} \qquad (1)$$

[1] The warming potential of methane is concentrated in the beginning of its atmospheric life-time (12.4 years).

[2] We first estimated linear and polynomial specifications. Polynomial models including a squared income term did not provide evidence for a polynomial relationship between income and emissions (see online appendix). Thus, we estimated threshold specifications, keeping only control variables that were statistically significant in the linear models.

E_{it} is annual (logged) methane emissions per capita of region i in period t, subsequently from production, final production, and consumption inventories. y_{it} is the logarithm of real GDP per capita (PPP adjusted), a_{it} is a dummy for Annex I membership to the Kyoto Protocol, t_{it} measures trade openness, and Z_{it} is a vector of controls. β_k, γ_1, and γ_2 are the coefficients of interest, δ is a coefficient vector associated with a set of controls, ν_t and μ_i are vectors of time- and individual fixed effects (FE), and $u_{it} \sim N(0, \sigma^2)$ are the disturbances. The inclusion of FE eliminates omitted variable bias from time-invariant country-specific factors, and from global time-varying factors. The indicator function $I(\cdot)$ determines regimes with different income elasticities, which depend on whether the threshold variable q_{it} (the logarithm of GDP per capita PPP five years lagged) is included in the estimated threshold interval $(\tau_{k-1}, \tau_k]$; $k = 1, \ldots, m$, where m is the number of regimes. The thresholds τ_k are contained in the domain of q_{it}, ($\tau_k \in [q_{it}^{min}, q_{it}^{max}]$), where $\tau_0 < q_{it}^{min}$ and $\tau_m = q_{it}^{max}$. After double-demeaning cancels ν_t and μ_i, threshold estimation is implemented through a grid search, where the range of q_{it} is restricted such that at least 15% of the observations lie in any regime in order to avoid regimes with too few observations. The parameters are estimated by constrained OLS (see Hansen, 1999).

We also account for potential endogeneities by instrumenting current income with 3-year lagged income, and Annex I membership with the ratification of the Rome Statute of the International Criminal Court (ICC). Regime-specific effects of income are instrumented using regime-specific terms for lagged income.[3] The instrumental variable (IV) threshold models are also estimated through a similar grid search, using 2-stage generalized methods of moments (GMM; see Caner and Hansen, 2004).

Data on methane emissions are available from Fernández-Amador et al. (2017b), consisting of a panel of 78 regions (comprising 178 countries) for the years 1997, 2001, 2004, 2007, and 2011. The other variables were sourced from the WDI database (GDP per capita, population density, fossil fuel rents, urbanization), the GTAP database (trade openness, food exports, fossil fuel exports), Polity IV (political regime), the HDI database (development categories), and the UN Treaty Collection Database (ratification of the Annex I of the Kyoto Protocol and Rome Statute of the ICC).

3 Results

The results in Table 1 provide evidence for the existence of a threshold effect in all three emission inventories. All detected thresholds are statistically significant and well defined, as indicated by their rather narrow confidence intervals.

[3] For the choice of the instruments see Aichele and Felbermayr (2012, 2015), Fernández-Amador et al. (2017a), and Frankel and Rose (2005).

	Panel (1) FE			Panel (2) IV-FE		
	prod.	fin.prod.	cons.	prod.	fin.prod.	cons.
ln(Income), reg. 1	0.270***	0.295***	0.328***	0.202**	0.268***	0.326***
	(0.060)	(0.058)	(0.066)	(0.080)	(0.077)	(0.093)
ln(Income), reg. 2	0.259***	0.284***	0.315***	0.188**	0.255***	0.311***
	(0.060)	(0.058)	(0.067)	(0.082)	(0.078)	(0.095)
Annex I	0.005	0.076***	0.101***	0.060	0.138**	0.159***
	(0.025)	(0.023)	(0.031)	(0.076)	(0.061)	(0.057)
Openness	0.137**	0.150**	0.067	0.132**	0.149**	0.072
	(0.064)	(0.075)	(0.083)	(0.061)	(0.069)	(0.077)
Fossil rents	-1.253**	-1.066**		-1.035*	-0.804	
	(0.621)	(0.496)		(0.622)	(0.513)	
First threshold (value)	10.429	10.421	10.421	10.429	10.405	10.405
99% CI lower bound	10.380	10.388	10.382	10.402	10.402	10.388
99% CI upper bound	10.489	10.489	10.489	10.489	10.445	10.431
Bootstrap p-value	0.022	0.002	0.000	0.008	0.000	0.000
SSR no threshold	3.540	2.873	3.929	3.561	2.889	3.939
SSR one threshold	3.374	2.697	3.701	3.451	2.797	3.803
Wald equal. Coeff. Reg 1/2 (p)	0.000	0.000	0.000	0.003	0.000	0.000
Wu-Hausman Inc, reg.1 (p)				0.621	0.861	0.789
Wu-Hausman Inc, reg.2 (p)				0.066	0.063	0.224
Wu-Hausman Annex I (p)				0.381	0.127	0.092
Kleibergen-Paap LM (p)				0.000	0.000	0.000
R^2 within (country, time)	0.171	0.238	0.194	0.152	0.209	0.171
N regime 1	319	315	315	319	311	311
N regime 2	71	75	75	71	79	79

Table 1: Threshold results. Cluster robust standard errors (Stock and Watson, 2008) in parentheses. The threshold value of 10.405 refers to the (log) GDP per capita of Germany in 1992, 10.421 to Italy in 1996, and 10.429 to Germany in 1996. CI stands for confidence interval. The upper bound of the CI is truncated at 10.489 as a result of the 15% trimming.

The positive relation between income and all three emission inventories slightly decreases in magnitude when moving from the first (low) to the second (high) income-regime. The thresholds that separate these regimes correspond to a log-income level of about 10.4 (33,000–34,000 PPP$). The difference in income elasticities across regimes is highly statistically significant (see Wald tests) but of small magnitude (about 0.01 percentage points), indicating that the methane-efficiency gains from economic growth are very limited.

The income-elasticity of methane emissions is highest for the consumption inventory—a one-percent increase in income per capita is connected to a 0.31–0.33 percent increase in consumption-based emissions. The income-elasticity of methane embodied in final production lies between 0.25–0.30, while the elasticity of production-based methane is the lowest (0.19–0.27). Thus, our results provide evidence for relative decoupling: an increase in income is connected to a less-than-proportional increase in emissions.

Annex I membership does not significantly affect methane emissions contained in production, while it is connected to higher methane embodied in final production and consumption. Trade openness is associated with higher methane emissions from territorial and final production, what, together with the results for Annex I membership, is consistent with the hypothesis of methane leakage. Finally, higher fossil fuel rents as a share of GDP are connected to lower emissions from territorial and final production. An analysis of the specific effects of the three sources for fossil fuels (oil, gas, coal) showed that this effect relates only to rents from oil and gas production. This may point to a sectoral composition effect resulting from the high specialization of the countries producing oil and gas. This result deserves further exploration in future research. All the other controls were statistically insignificant.[4]

4 Conclusion

Discussions on climate change mitigation have been accompanied by extensive research on CO_2 emissions, whereas empirical evidence on the socio-economic drivers of methane is limited and a theoretical framework is missing. Our study unveils important empirical differences between methane and CO_2 (see Fernández-Amador et al., 2017a, for comparison). First, the income-elasticity of methane per capita is two to three times smaller than the income-elasticity of CO_2 per capita, suggesting that regulations aimed at reducing methane emissions do not necessarily compromise economic growth targets. Second, methane emissions embodied in (final production and) consumption are higher in Annex I members, whereas CO_2 consumption-based emissions are not affected by Annex I membership. Finally, unlike for CO_2, higher rents from fossil fuels as a share of GDP are related to lower methane emissions from territorial and final production, whereas a higher population density is not related to lower methane emissions per capita.

To be effective, environmental regulation must address the responsibility for emissions, taking into account the particularities of methane. Research should develop a theoretical framework on the relationship of economic growth and methane emissions that encompasses our findings.

[4] We controlled for the influence of food exports and fuel exports (% of total exports), (logged) population density, urbanization, fossil rents (% of GDP), political regimes, and development-group dummies. For threshold specifications we kept only variables that were statistically significant in the linear models.

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A Online Appendix

A.1 Definition of regions

Aggregate	Countries and regions included
	Single Countries and Regions:
The 66 single countries and regions	Albania, Argentina, Australia, Austria, Belgium, Bangladesh, Bulgaria, Brazil, Botswana, Canada, Chile, China, Colombia, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hong Kong, Hungary, India, Indonesia, Ireland, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Malawi, Malaysia, Malta, Mexico, Morocco, Mozambique, Netherlands, New Zealand, Peru, Philippines, Poland, Portugal, Romania, Russia, Singapore, Slovakia, Slovenia, Spain, Sri Lanka, Sweden, Switzerland, Taiwan, Tanzania, Thailand, Turkey, Uganda, United Kingdom, United States, Uruguay, Venezuela, Vietnam, Zambia, Zimbabwe
	The 12 Composite Regions:
Rest of Andean Pact	Bolivia and Ecuador
Central America, Caribbean	Anguilla, Antigua & Barbados, Aruba, Bahamas, Barbados Belize, Cayman Islands, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Netherlands Antilles, Nicaragua, Panama, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago and Virgin Islands (GB)
Rest of EFTA	Iceland, Liechtenstein and Norway
Rest of Former Soviet Union	Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan
Middle East	Bahrain, Iran (Islamic Republic of), Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Rep., United Arab Emirates and Yemen
Rest of North Africa	Algeria, Egypt, Libyan Arab Jamahiriya and Tunisia
Other Southern Africa	Angola and Congo (DPR)
Rest of South African Customs Union	Lesotho, Namibia, South Africa and Swaziland
Rest of South America	Guyana, Paraguay and Suriname
Rest of South Asia	Bhutan, Maldives, Nepal and Pakistan
Rest of Sub-Saharan Africa	Benin, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Cote d'Ivoire, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Madagascar, Mali, Mauritania, Mayotte, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, Sudan, Togo and Mauritius
Rest of World	Afghanistan, Albania, Andorra, Bermuda, Bosnia and Herzegovina, Brunei, Cambodia, Faroe Islands, Fiji, French Polynesia, Gibraltar, Greenland, Guadeloupe, Kiribati, Lao (PDR), Macau, Macedonia (former Yugoslav Republic of), Marshall Islands, Micronesia, Monaco, Mongolia, Myanmar, Nauru, New Caledonia, Korea (DPR), Papua New Guinea, San Marino, Solomon Islands, Tonga, Tuvalu, Vanuatu, Western Samoa, Rest of former Yugoslavia

Table A.1: Definition of regions. Countries and 12 composite regions are defined as in Fernández-Amador et al. (2017b).

A.2 Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
		Dependent variables			
ln(CH_4 prod.)	390	0.048	0.684	-1.629	2.012
ln(CH_4 fin. prod.)	390	0.237	0.590	-1.364	1.748
ln(CH_4 cons.)	390	0.245	0.581	-1.381	1.654
		Independent variables			
ln(Income)	390	9.498	1.101	6.205	11.491
Annex I	390	0.279	0.449	0	1
Openness	390	0.821	0.475	0.176	3.274
Fossil rents	390	0.028	0.058	0.000	0.406
ln(Pop. density)	390	-2.603	1.458	-6.028	1.996
Food exports (%)	390	0.123	0.130	0.002	0.759
Fuel exports (%)	390	0.135	0.199	0.000	0.944
Urbanization	390	0.629	0.216	0.118	1.000
Polity IV	390	6.226	5.122	-7.000	10.000
HDI middle	390	0.215	0.412	0	1
HDI high	390	0.238	0.427	0	1
HDI very high	390	0.408	0.492	0	1
		Instrumental variables			
ICC ratification	390	0.305	0.461	0	1
ln(Income), lag 3	390	9.413	1.116	5.936	11.461

Table A.2: Descriptive statistics

A.3 First stage results

The results of the first-stage regressions corresponding to the FE-IV threshold models reported in the main text are shown in Tables A.3–A.5. First-stage regressions for all subsequent specifications that are reported in the online appendix are not shown but are available from the authors upon request.

	CH_4 production		
	ln(Inc), reg1	ln(Inc), reg2	Annex I
ln(Income), reg. 1, lag 3	0.754***	0.032**	0.188
	(0.044)	(0.014)	(0.115)
ln(Income), reg. 2, lag 3	-0.256***	1.036***	0.210*
	(0.044)	(0.014)	(0.117)
ICC	0.005	-0.007	0.492***
	(0.016)	(0.005)	(0.068)
Openness	-0.064**	-0.007	0.039
	(0.031)	(0.008)	(0.112)
Fossil rents	0.773**	0.029	-2.046***
	(0.352)	(0.045)	(0.707)
R^2	0.999	1.000	0.350
N	390	390	390

Table A.3: Instrumentation – CH_4 production

	CH_4 final production		
	ln(Inc), reg1	ln(Inc), reg2	Annex I
ln(Income), reg. 1, lag 3	0.754***	0.035**	0.150
	(0.044)	(0.015)	(0.116)
ln(Income), reg. 2, lag 3	-0.255***	1.039***	0.164
	(0.044)	(0.015)	(0.118)
ICC	0.005	-0.006	0.511***
	(0.016)	(0.006)	(0.067)
Openness	-0.066**	-0.005	0.036
	(0.031)	(0.009)	(0.110)
Fossil rents	0.774**	0.039	-2.199***
	(0.350)	(0.047)	(0.724)
R^2	0.999	1.000	0.331
N	390	390	390

Table A.4: Instrumentation – CH_4 final production

	CH_4 consumption		
	ln(Inc), reg1	ln(Inc), reg2	Annex I
ln(Income), reg. 1, lag 3	0.745***	0.035**	0.177
	(0.044)	(0.015)	(0.116)
ln(Income), reg. 2, lag 3	-0.265***	1.039***	0.192
	(0.044)	(0.015)	(0.118)
ICC	-0.004	-0.007	0.537***
	(0.017)	(0.005)	(0.065)
Openness	-0.059*	-0.005	0.018
	(0.031)	(0.009)	(0.114)
R^2	0.999	1.000	0.316
N	390	390	390

Table A.5: Instrumentation – CH_4 consumption

A.4 Linear model specification

We first estimated linear and polynomial FE and IV-FE specifications. Table A.6 shows the results of the linear FE and IV-FE specifications for the full set of regressors. Polynomial FE and IV-FE models including a squared income term (reported in Table A.8) did not provide evidence for a polynomial relationship between income and emissions, while cubic polynomials (reported in Table A.9) did not provide a good fit to the data. Therefore, we subsequently estimated the linear models while dropping regressors that were not statistically significant at least at the 10% level (Table A.7) to optimize the efficiency of our estimations (restricted models), what we regard as particularly important when threshold effects are to be introduced. Our baseline regressors, income, Annex I membership, and openness, were always included in the estimations.

	Panel (1) FE			Panel (2) IV-FE		
	prod.	fin.prod.	cons.	prod.	fin.prod.	cons.
ln(Income)	0.334***	0.347***	0.387***	0.276***	0.327***	0.382***
	(0.072)	(0.067)	(0.081)	(0.079)	(0.093)	(0.117)
Annex I	-0.019	0.063**	0.093**	0.018	0.124	0.165*
	(0.028)	(0.027)	(0.038)	(0.112)	(0.091)	(0.094)
Openness	0.160**	0.164**	0.088	0.156**	0.166**	0.092
	(0.066)	(0.079)	(0.093)	(0.067)	(0.076)	(0.087)
ln(Pop. density)	0.155	0.235	0.315	0.205	0.362	0.473
	(0.188)	(0.189)	(0.208)	(0.318)	(0.288)	(0.311)
Food exports (%)	0.033	0.016	-0.106	0.037	0.049	-0.062
	(0.127)	(0.150)	(0.212)	(0.130)	(0.156)	(0.212)
Fuel exports (%)	0.035	-0.164	0.004	0.050	-0.136	0.037
	(0.072)	(0.101)	(0.150)	(0.082)	(0.093)	(0.143)
Urbanization	-0.168	0.152	0.169	-0.063	0.278	0.306
	(0.500)	(0.518)	(0.538)	(0.624)	(0.586)	(0.611)
Polity IV	-0.001	0.002	0.004	-0.001	0.002	0.004
	(0.003)	(0.004)	(0.003)	(0.003)	(0.004)	(0.004)
Fossil rents	-1.265**	-0.959*	-0.770	-1.171**	-0.867*	-0.678
	(0.606)	(0.492)	(0.603)	(0.582)	(0.501)	(0.610)
HDI middle	-0.054	-0.039	-0.016	-0.034	-0.022	-0.001
	(0.043)	(0.042)	(0.060)	(0.042)	(0.046)	(0.065)
HDI high	-0.044	0.010	0.063	-0.011	0.041	0.093
	(0.053)	(0.049)	(0.069)	(0.057)	(0.057)	(0.077)
HDI very high	-0.009	0.031	0.094	0.027	0.061	0.122
	(0.065)	(0.067)	(0.080)	(0.064)	(0.075)	(0.088)
Wu-Hausman Inc (p)				0.680	0.350	0.714
Wu-Hausman Annex I (p)				0.283	0.453	0.254
Kleibergen-Paap LM (p)				0.000	0.000	0.000
R^2 (within)	0.164	0.230	0.193	0.156	0.210	0.173
N	390	390	390	390	390	390

Table A.6: Linear model

Table A.7 reports the results of the restricted models. The threshold estimations reported in the main text of the article are based on these restricted models.

	Panel (1) FE			Panel (2) IV-FE		
	prod.	fin.prod.	cons.	prod.	fin.prod.	cons.
ln(Income)	0.318***	0.345***	0.386***	0.266***	0.322***	0.385***
	(0.064)	(0.061)	(0.071)	(0.077)	(0.078)	(0.096)
Annex I	-0.022	0.049**	0.069**	0.000	0.074	0.089*
	(0.025)	(0.024)	(0.030)	(0.065)	(0.057)	(0.053)
Openness	0.145**	0.156**	0.076	0.141**	0.155**	0.078
	(0.067)	(0.077)	(0.087)	(0.066)	(0.075)	(0.085)
Fossil rents	-1.147*	-0.941*		-1.026	-0.820	
	(0.633)	(0.511)		(0.630)	(0.525)	
Wu-Hausman Inc				0.273	0.512	0.964
Wu-Hausman Annex I (p)				0.660	0.518	0.498
Kleibergen-Paap LM (p)				0.000	0.000	0.000
R^2 (within)	0.155	0.203	0.154	0.150	0.199	0.152
N	390	390	390	390	390	390

Table A.7: Restricted linear model

A.5 Polynomial specifications

The results of the polynomial model of order two, reported in Table A.8, do not provide evidence for the existence of a non-linear relationship between income and emissions.

The results of the estimation of a cubic model, reported in Table A.9, indicate that for some emission inventories all three income terms are statistically significant, suggesting that emissions decrease with increasing income at low income levels, increase at medium income levels, and decrease again at high income levels. Yet, the first (lower) turning point lies out of sample for the FE specifications and for the IV-FE regressions only a maximum of 1.8% of the observations fall below the first turning point. Similarly, the values of the second (higher) turning point imply that only a small share of the observations in our sample lie above it (max. 4.1%). The majority of observations is thus subject to a positive effect of income on emissions, with a decreasing slope towards the end of the sample.

Because very few observations fall in the areas of negative income-elasticity (first and third regimes), this may be an artifact from imposing a cubic specification that does not fit the data well, which may still be well characterized by a non-linear relationship of a different functional form. Since the polynomial specifications seem to impose a very restrictive functional form that does not fit the data appropriately, we aim to capture the relationship between income and methane emissions per capita with threshold models, which assume a piecewise-linear specification and place less restrictions on the functional form of the relationship. The results reported in the main text of the article suggest that

	Panel (1) FE			Panel (2) IV-FE		
	prod.	fin.prod.	cons.	prod.	fin.prod.	cons.
ln(Income)	-1.146	-0.499	-0.777	-0.494	-0.103	-0.530
	(0.736)	(0.589)	(0.769)	(0.628)	(0.734)	(0.849)
ln(Income), squared	0.087*	0.050	0.068	0.045	0.025	0.053
	(0.045)	(0.035)	(0.046)	(0.039)	(0.045)	(0.052)
Annex I	-0.028	0.057**	0.086**	0.002	0.115	0.146
	(0.026)	(0.027)	(0.039)	(0.106)	(0.091)	(0.095)
Openness	0.178***	0.175**	0.102	0.164***	0.171**	0.102
	(0.057)	(0.077)	(0.086)	(0.061)	(0.074)	(0.083)
ln(Pop. density)	0.413*	0.383	0.518*	0.313	0.422	0.601*
	(0.246)	(0.250)	(0.273)	(0.336)	(0.333)	(0.356)
Food exports (%)	-0.044	-0.028	-0.167	-0.011	0.022	-0.118
	(0.148)	(0.146)	(0.199)	(0.138)	(0.156)	(0.205)
Fuel exports (%)	0.056	-0.152	0.020	0.055	-0.133	0.044
	(0.074)	(0.097)	(0.144)	(0.082)	(0.092)	(0.140)
Urbanization	0.077	0.292	0.362	0.042	0.337	0.431
	(0.526)	(0.512)	(0.519)	(0.617)	(0.587)	(0.591)
Polity IV	-0.000	0.003	0.004	-0.000	0.003	0.004
	(0.003)	(0.004)	(0.003)	(0.003)	(0.004)	(0.004)
Fossil rents	-1.259**	-0.956**	-0.766	-1.183**	-0.873*	-0.691
	(0.494)	(0.428)	(0.508)	(0.519)	(0.468)	(0.537)
HDI middle	-0.014	-0.016	0.015	-0.015	-0.012	0.021
	(0.039)	(0.040)	(0.056)	(0.043)	(0.045)	(0.061)
HDI high	-0.003	0.033	0.095	0.005	0.050	0.113
	(0.046)	(0.046)	(0.062)	(0.057)	(0.054)	(0.071)
HDI very high	0.020	0.047	0.116	0.038	0.067	0.134
	(0.060)	(0.065)	(0.075)	(0.065)	(0.072)	(0.083)
Wu-Hausman Inc (p)				0.285	0.476	0.753
Wu-Hausman Inc, sq. (p)				0.263	0.445	0.731
Wu-Hausman Annex I (p)				0.760	0.408	0.364
Kleibergen-Paap LM (p)				0.000	0.000	0.000
R^2 (within)	0.200	0.243	0.213	0.187	0.224	0.199
N	390	390	390	390	390	390

Table A.8: Full model – squared specification

	Panel (1) FE			Panel (2) IV-FE		
	prod.	fin.prod.	cons.	prod.	fin.prod.	cons.
ln(Income)	0.999	-6.117*	-9.039*	-1.972	-10.065**	-12.286**
	(4.146)	(3.086)	(4.725)	(4.307)	(4.177)	(6.172)
ln(Income), squared	-0.157	0.687*	1.006*	0.214	1.162**	1.395**
	(0.497)	(0.365)	(0.550)	(0.506)	(0.478)	(0.696)
ln(Income), cubic	0.009	-0.024*	-0.035	-0.006	-0.043**	-0.050*
	(0.020)	(0.014)	(0.021)	(0.020)	(0.018)	(0.026)
Annex I	-0.033	0.069**	0.104**	0.010	0.175*	0.217**
	(0.027)	(0.027)	(0.041)	(0.120)	(0.105)	(0.109)
Openness	0.172***	0.191**	0.126	0.169**	0.204***	0.142
	(0.057)	(0.079)	(0.090)	(0.072)	(0.078)	(0.088)
ln(Pop. density)	0.355	0.534**	0.741***	0.365	0.773*	1.015**
	(0.220)	(0.238)	(0.276)	(0.394)	(0.406)	(0.456)
Food exports (%)	-0.020	-0.089	-0.257	-0.022	-0.055	-0.208
	(0.135)	(0.147)	(0.197)	(0.134)	(0.150)	(0.189)
Fuel exports (%)	0.054	-0.149	0.026	0.059	-0.109	0.072
	(0.074)	(0.094)	(0.139)	(0.082)	(0.087)	(0.135)
Urbanization	0.121	0.176	0.191	0.019	0.178	0.243
	(0.584)	(0.503)	(0.494)	(0.620)	(0.563)	(0.559)
Polity IV	0.000	0.002	0.003	-0.001	0.001	0.003
	(0.003)	(0.004)	(0.004)	(0.003)	(0.004)	(0.004)
Fossil rents	-1.192**	-1.132***	-1.025**	-1.224**	-1.155***	-1.024**
	(0.502)	(0.389)	(0.464)	(0.511)	(0.413)	(0.492)
HDI middle	-0.008	-0.034	-0.011	-0.020	-0.041	-0.013
	(0.044)	(0.044)	(0.060)	(0.046)	(0.050)	(0.068)
HDI high	0.012	-0.005	0.038	-0.003	-0.010	0.042
	(0.056)	(0.052)	(0.069)	(0.061)	(0.060)	(0.079)
HDI very high	0.036	0.005	0.055	0.027	-0.002	0.054
	(0.064)	(0.072)	(0.077)	(0.069)	(0.075)	(0.087)
Turning point (TP) 1		12.306	12.010		11.109	11.312
Turning point (TP) 2		6.973	7.180		7.100	7.214
% below TP 1		0.0%	0.0%		1.8%	1.0%
% above TP 2		2.8%	3.8%		3.3%	4.1%
Wu-Hausman Inc (p)				0.293	0.606	0.898
Wu-Hausman Inc, sq. (p)				0.268	0.550	0.852
Wu-Hausman Inc, cub. (p)				0.249	0.500	0.808
Wu-Hausman Annex I (p)				0.729	0.224	0.172
Kleibergen-Paap LM (p)				0.003	0.003	0.003
R^2 (within)	0.202	0.258	0.237	0.182	0.202	0.191
N	390	390	390	390	390	390

Table A.9: Full model – cubic specification at high income levels the income-elasticity of emissions decreases. The detected threshold-intervals are quite narrowly defined, which points towards a better representation of the non-linear relationship between income and emission by threshold models as compared to polynomial specifications.

B Robustness

B.1 No Annex I control

We tested the robustness of our results to the exclusion of the Annex I membership dummy. Because Annex I membership is related to a high income per capita, part of the income effect could be captured by Annex I membership. Table B.1 reports the FE and IV-FE threshold results of this robustness check. For this robustness check, the results corresponding to the analyses shown in tables A.8-A.7 and the results of the first-stage regressions are not reported here, but are available from the authors.

The main results are not affected by the exclusion of Annex I membership. We detected threshold effects for all emission inventories. The income-elasticity of emissions per capita decreases a little when moving to a high-income regime at a similar threshold value as in the baseline analysis (i.e. around a log-income level of 10.4). The income-elasticities remain rather similar, with slightly larger values in the FE-IV specifications.

One difference to the baseline results is that in the models without the Annex I control we found evidence for the existence of two thresholds in the FE model for CH_4 consumption. The resulting coefficient estimates imply an increase in the income-elasticity of emissions when moving from the low to the medium income regime, and a decrease after moving to the high income regime.

	Panel (1) FE			Panel (2) IV-FE		
	prod.	fin.prod.	cons.	prod.	fin.prod.	cons.
ln(Income), reg. 1	0.270***	0.312***	0.300***	0.229***	0.324***	0.404***
	(0.059)	(0.056)	(0.066)	(0.068)	(0.070)	(0.092)
ln(Income), reg. 2	0.260***	0.303***	0.312***	0.218***	0.315***	0.395***
	(0.060)	(0.056)	(0.064)	(0.068)	(0.070)	(0.093)
ln(Income), reg. 3			0.304***			
			(0.065)			
Openness	0.137**	0.147*	0.073	0.133**	0.149*	0.065
	(0.063)	(0.082)	(0.094)	(0.063)	(0.082)	(0.093)
Fossil rents	-1.272**	-1.357***		-1.268**	-1.359***	
	(0.618)	(0.497)		(0.612)	(0.498)	
First threshold (value)	10.429	10.405	9.364	10.429	10.405	10.405
99% CI lower bound	10.380	10.382	9.248	10.388	10.382	10.382
99% CI upper bound	10.489	10.489	9.398	10.489	10.489	10.489
Bootstrap p-value	0.016	0.016	0.040	0.000	0.000	0.000
Second threshold (value)			10.405			
99% CI lower bound			10.306			
99% CI upper bound			10.489			
Bootstrap p-value			0.076			
Wald equal. Coeff. Reg 1/2 (p)	0.000	0.001	0.084	0.000	0.001	0.017
Wald equal. Coeff. Reg 2/3 (p)			0.018			
Wald equal. Coeff. Reg 1/3 (p)			0.672			
Wu-Hausman Inc, reg.1 (p)				0.898	0.503	0.187
Wu-Hausman Inc, reg.2 (p)				0.039	0.436	0.890
Kleibergen-Paap LM (p)				0.001	0.001	0.001
SSR no threshold	3.551	2.929	4.046	3.561	2.929	4.051
SSR one threshold	3.375	2.810	3.899	3.381	2.810	3.931
SSR two thresholds			3.795			
R2 within (country, time)	0.171	0.206	0.173	0.170	0.206	0.144
N regime 1	319	311	171	319	311	311
N regime 2	71	79	140	71	79	79
N regime 3			79			

Table B.1: Threshold results. Cluster robust standard errors (Stock and Watson, 2008) in parentheses. The threshold value of 10.429 refers to the (log) GDP per capita of Germany in 2006, 10.405 to Germany in 1992, and 9.364 to Turkey in 1992. CI stands for confidence interval. CI stands for confidence interval. The upper bound of the CI is truncated at 10.489 as a result of the 15% trimming.