Determinants of agricultural emissions: panel data evidence from a global sample

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ONLINE APPENDIX

Appendix A. Supplementary tables and figures

Table A1. Recent literature on the determinants of agricultural emissions

No	Authors	Countries	Data period	Theoretical framework	Methods	Main variables	Other variables	Main findings	Robustness check
1	Pazienza (2015)	Agriculture and fishing sector of 30 OECD countries	1981-2005	EKC	OLS, FEM, REM	FDI inflows and CO_2	Sectoral GDP per worker, Square of sectoral GDP per worker, Share of sectoral GDP to total GDP, Education, Surface of Protected area	FDI $\rightarrow CO_2$ (-)	Analyzing the technique, scale and cumulative effects of FDI
2	Al-mulali et al. (2016)	15 countries	1990–2007	No	Panel unit root test, Panel cointegration tests, Panel Granger causality test	Foreign investments in agriculture, domestic investments in agriculture, agricultural output, and greenhouse gases emissions from agriculture		A long-run causal relationship exists among all the variables. Agricultural output $\Leftrightarrow$ greenhouse gases emissions from agriculture. Foreign investments in agriculture $\neq$ greenhouse gases emissions from agriculture	No
3	Audet et al. (2017)	Sweden	2014-2015	No	An agricultural catchment			Agricultural streams are a significant source of N_2O.	No
4	Mehdi and Slim (2017)	Algeria, Egypt, Morocco, Sudan, Tunisia	1980-2011	No	Granger causality and Cointegration	Renewable energy consumption, Agricultural value added, CO_2		Short-run and long-run bidirectional causal relations exist between CO_2 and agriculture.	No

5	Chen et al. (2017)	China Agriculture		No	A two-stage game and the game timing			Pollution-reducing innovation subsidies are more efficient than quantity subsidies in reducing agricultural emissions.	No
6	Yan et al. (2017)	17 European countries	1995-2012	No	Generalized Divisia Index method	Agricultural output, Energy consumption, GHG emissions, Energy intensity		France, Latvia, and Belgium witness the increase in GHG emissions. Energy intensity and scale of agricultural production in France are main reasons. Increase in carbon factor is main cause in Latvia and Belgium	No
7	Luo et al. (2017)	30 Chinese provinces	1997-2014	No	Tapio decoupling method	CO_2 emissions, and agricultural output		Fertilizer and cattle are main drivers of CO_2 emissions in Agriculture	No
8	Castesana et al. (2018)	Argentina	2000-2012	No	Estimations			Mineral fertilizers, manure in pasture, manure management, agricultural waste burning are main contributors of NH_3 emissions in agriculture	No
9	Coderoni and Esposti (2018)	6542 Italian farms	2003-2007	No	Multinomial Logit models	Common Agricultural Policy (CAP) and agricultural GHG emissions		CAP expenditure has helped reduce farm-level emissions, but it is differ across farms	No
10	Kastratović (2019)	63 developing countries	2005-2014	No	Generalized method of moments (GMM)	CO_2 in agriculture, FDI in agriculture, Export of agriculture, GDP per capita	Import, Internet users, Environmental regulations, Livestock productions, Oil price	FDI→CO_2 (+)	By time periods: 2005-2014; 2005-2012; 2006-2014; and 2007-2014

Notes: TRADE → CO_2 means that the causality runs from trade to CO_2 emissions. FDI → CO_2 means that the causality runs from FDI inflows to CO_2 emissions. Trade/FDI ⇔ CO_2 means that bi-directional causality exists between Trade/FDI and CO_2 emissions. Trade/FDI ≠ CO_2 means that no causality exists between Trade/FDI and CO_2 emissions. EN: energy consumption, EP: energy production; GDP: gross domestic product, FDI: foreign direct investment, Trade: trade openness.

Table A2a. List of countries

High income economies (31)				
Australia	Finland	Ireland	New Zealand	Spain
Austria	France	Israel	Norway	Sweden
Chile	Germany	Italy	Poland	Switzerland
Cyprus	Greece	Japan	Portugal	United Kingdom
Czech Republic	Hungary	Latvia	Saudi Arabia	United States
Denmark	Iceland	Lithuania	Slovenia	
Estonia				
Upper-middle income economies (26)				
Albania	Brazil	Croatia	Mauritius	Romania
Algeria	Bulgaria	Dominican Republic	Mexico	Russian Federation
Argentina	China	Ecuador	Namibia	South Africa
Azerbaijan	Colombia	Kazakhstan	Paraguay	Thailand
Belarus	Costa Rica	Malaysia	Peru	Turkey
Botswana				
Low and lower-middle income economies (32)				
Armenia	Congo, Rep.	Kenya	Nicaragua	Tajikistan
Bangladesh	El Salvador	Moldova	Nigeria	Tanzania
Benin	Georgia	Mongolia	Pakistan	Togo
Bolivia	Ghana	Morocco	Philippines	Tunisia
Cambodia	Honduras	Mozambique	Senegal	Ukraine
Cameroon	India	Nepal	Sri Lanka	Zambia
Congo, Dem. Rep.	Jordan			

Note: The income classification follows the World Bank's country classification. See https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups .

Table A2b. Missing data for 68 excluded countries

Variables		Countries with missing data for some years or the full sample period (1995-2012)
Dependent variable	AE	Belgium, Luxembourg, Montenegro, Serbia, Zimbabwe
	ME	
	NE	
Explanatory variables	Income	Eritrea, Syrian Arab. Rep.
	Agri	Angola, Bahrain, Cabo Verde, Canada, Comoros, Côte d'Ivoire, Equatorial Guinea, Eritrea, Gabon, Gambia, Guatemala, Haiti, Hong Kong, Iceland, Indonesia, Kuwait, Myanmar, Niger, Oman, Papua New Guinea, Qatar, Rwanda, Singapore, Solomon Islands, Syrian Arab. Rep., Vietnam, Yemen, Zimbabwe
	Energy	Bahamas, Belize, Bhutan, Burkina Faso, Burundi, Cabo Verde, Central African Republic, Chad, Comoros, Equatorial Guinea, Eritrea, Fiji, Gambia, Guinea, Guinea-Bissau, Guyana, Laos, Lesotho, Liberia, Madagascar, Malawi, Maldives, Mali, Mauritania, Myanmar, Niger, Papua New Guinea, Rwanda, Sierra Leone, Solomon Islands, Suriname, Swaziland, Syrian Arab. Rep., Uganda, Yemen, Zimbabwe
	Trade	Angola, Eritrea, Ethiopia, Guinea, Jamaica, Jordan, Lesotho, Liberia, Maldives, Myanmar, Papua New Guinea, Syrian Arab. Rep., United Arab Emirates
	Export	Angola, Eritrea, Ethiopia, Guinea, Jamaica, Jordan, Lesotho, Liberia, Maldives, Myanmar, Papua New Guinea, Syrian Arab. Rep., United Arab Emirates
	Import	Angola, Eritrea, Ethiopia, Guinea, Jamaica, Jordan, Lesotho, Liberia, Maldives, Myanmar, Papua New Guinea, Syrian Arab. Rep., United Arab Emirates
	FDI	Belgium, Belize, Bhutan, Bosnia and Herzegovina, Brunei Darussalam, Burundi, Eritrea, Gambia, Georgia, Greece, Hong Kong, Lebanon, Luxembourg, Myanmar, Nepal, Syrian Arab. Rep.

Table A3. Variables, definitions, and data sources

Variables		Definitions	Source	Time coverage
Dependent variable	AE	Log of Total emissions from Agriculture (kg CO_2 equivalent) per capita	CAIT Climate Data Explorer (2015)	1990-2012
	ME	Log of Agricultural methane emissions (kg of CO_2 equivalent) per capita	WDI	1970-2008
	NE	Log of Agricultural nitrous oxide emissions (kg of CO_2 equivalent) per capita	WDI	1970-2008
Explanatory variables	Income	Log of GDP per capita (constant 2010 US$)	WDI	1960-2017
	Agri	Log of Agriculture value added (% of GDP)	WDI	1968-2017
	Energy	Log of Energy use (kg of oil equivalent per capita)	WDI	1990-2014
	Trade	Log of Trade value per capita	WDI	1960-2017
	Export	Log of Exports of goods and services value per capita	WDI	1960-2017
	Import	Log of Imports of goods and services value per capita	WDI	1960-2017
	FDI	Foreign direct investment, net inflows (% of GDP)	WDI	1970-2017

Notes: WDI is the World Development Indicators (version 2017) from the World Bank. The data of ME and NE are available from 1970 to 2008 for the majority of the countries globally, but the data on the agriculture value-added variable is mostly available from 1995 for most of the countries. Therefore, the periods 1995–2012 and 1995–2008 are used for the CO_2 model (1995–2012) and the ME and NE models (1995–2008), subject to the availability of all the required data for a global sample of 89 countries.

Table A4. Data description for subsamples

Variables	Obs	Mean	SD.	Min	Max
High income economies (31)					
Log of Total emissions from Agriculture (kg CO2 equivalent) per capita	558	6.93	0.93	5.13	9.28
Log of Agricultural methane emissions (kg of CO2 equivalent) per capita	434	6.31	0.92	4.34	8.79
Log of Agricultural nitrous oxide emissions (kg of CO2 equivalent) per capita	434	6.09	0.83	4.14	8.08
Log of GDP per capita (constant 2010 US$)	558	10.20	0.65	8.54	11.43
Log of Agriculture value added (% of GDP)	554	10.93	0.60	9.50	12.82
Log of Energy use (kg of oil equivalent) per $1,000 GDP (constant 2011 PPP)	558	8.16	0.48	6.63	9.81
Log of Trade value per capita	558	14.18	0.85	11.99	16.20
Log of Exports of goods and services value per capita	558	13.49	0.89	11.30	15.57
Log of Imports of goods and services value per capita	558	13.48	0.82	11.24	15.43
Foreign direct investment, net inflows (% of GDP)	557	4.47	10.19	-43.46	198.07
Upper-middle income economies (26)					
Log of Total emissions from Agriculture (kg CO2 equivalent) per capita	468	6.84	0.79	4.64	9.01
Log of Agricultural methane emissions (kg of CO2 equivalent) per capita	364	6.30	0.91	3.49	8.01
Log of Agricultural nitrous oxide emissions (kg of CO2 equivalent) per capita	364	5.90	0.75	4.37	7.87
Log of GDP per capita (constant 2010 US$)	468	8.58	0.49	7.10	9.60
Log of Agriculture value added (% of GDP)	468	10.33	0.55	8.98	11.69
Log of Energy use (kg of oil equivalent) per $1,000 GDP (constant 2011 PPP)	468	7.16	0.59	5.95	8.55
Log of Trade value per capita	468	12.42	0.84	9.96	14.29
Log of Exports of goods and services value per capita	468	11.71	0.88	8.85	13.70
Log of Imports of goods and services value per capita	468	11.73	0.83	9.21	13.51
Foreign direct investment, net inflows (% of GDP)	467	4.14	5.25	-0.88	55.08
Low and lower-middle income economies (32)					
Log of Total emissions from Agriculture (kg CO2 equivalent) per capita	576	6.45	0.68	4.86	8.91
Log of Agricultural methane emissions (kg of CO2 equivalent) per capita	448	6.03	0.69	4.13	8.17
Log of Agricultural nitrous oxide emissions (kg of CO2 equivalent) per capita	448	5.50	0.75	3.88	7.75
Log of GDP per capita (constant 2010 US$)	576	7.07	0.69	5.14	8.33
Log of Agriculture value added (% of GDP)	576	9.68	0.55	8.24	11.30
Log of Energy use (kg of oil equivalent) per $1,000 GDP (constant 2011 PPP)	576	6.21	0.54	4.88	8.06
Log of Trade value per capita	573	10.98	0.98	8.26	13.11

Log of Exports of goods and services value per capita	573	10.12	1.02	7.52	12.54
Log of Imports of goods and services value per capita	573	10.41	0.98	7.50	12.60
Foreign direct investment, net inflows (% of GDP)	572	3.87	4.65	-4.84	43.91

Table A5. Data descriptions

Variables	Obs	Mean	SD.	Min	Max
Log of Total emissions from Agriculture (kg CO_2 equivalent) per capita	1,602	6.73	0.83	4.64	9.28
Log of Agricultural methane emissions (kg of CO_2 equivalent) per capita	1,246	6.20	0.85	3.49	8.79
Log of Agricultural nitrous oxide emissions (kg of CO_2 equivalent) per capita	1,246	5.82	0.82	3.88	8.08
Log of GDP per capita (constant 2010 US$)	1,602	8.60	1.46	5.14	11.43
Log of Agriculture value added (% of GDP)	1,599	12.52	1.62	8.26	16.20
Log of Energy use (kg of oil equivalent) per capita	1,599	11.76	1.70	7.52	15.57
Log of Trade value per capita	1,602	6.73	0.83	4.64	9.28
Log of Exports of goods and services value per capita	1,246	6.20	0.85	3.49	8.79
Log of Imports of goods and services value per capita	1,246	5.82	0.82	3.88	8.08
FDI, net inflows (% of GDP)	1,602	8.60	1.46	5.14	11.43

Notes: Due to data availability, the data of CH_4 and N_2O emissions are from 1995 to 2008, and the data of total emissions are from 1995 to 2012. That is why the average sum of the two emissions (CH_4 and N_2O) is higher than the total emissions.

Table A6. Correlation matrix

Correlation p-value in ()	AE	ME	NE	Income	Agri	Energy	Trade	Export	Import	FDI
AE	1.00									
ME	0.92*** 0.00	1.00								
NE	0.89*** 0.00	0.83*** 0.00	1.00							
Income	0.19*** 0.00	0.10*** 0.00	0.27*** 0.00	1.00						
Agri	0.30*** 0.00	0.20*** 0.00	0.33*** 0.00	0.77*** 0.00	1.00					
Energy	0.20*** 0.00	0.07*** 0.01	0.29*** 0.00	0.89*** 0.00	0.67*** 0.00	1.00				
Trade	0.16*** 0.00	0.05* 0.08	0.25*** 0.00	0.94*** 0.00	0.78*** 0.00	0.84*** 0.00	1.00			
Export	0.16*** 0.00	0.05* 0.06	0.25*** 0.00	0.94*** 0.00	0.77*** 0.00	0.84*** 0.00	0.99*** 0.00	1.00		
Import	0.16*** 0.00	0.05* 0.10	0.25*** 0.00	0.93*** 0.00	0.78*** 0.00	0.83*** 0.00	0.99*** 0.00	0.99*** 0.00	1.00	
FDI	0.03 0.17	0.03 0.35	0.08*** 0.00	0.03 0.22	0.01 0.57	0.06** 0.02	0.10*** 0.00	0.09*** 0.00	0.11*** 0.00	1.00

Note: *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A7. Pesaran CD-test for cross-sectional dependence and Pesaran (2007)'s panel unit root test

Variable	CD-test	CIPS for level	CIPS for 1st difference
AE	37.55***	-2.164**	-4.088***
ME	51.70***	-1.393	-3.248***
NE	17.95***	-1.944	-3.574***
Income	218.3***	-1.820	-2.763***
Agri[a]	179.2***	-2.487***	-3.629***
Energy	49.03***	-2.313	-3.705***
Trade[b]	249.0***	-2.057*	-3.360***
Export[b]	241.5***	-2.020*	-3.298***
Import[b]	243.5***	-1.919	-3.051***
FDI[c]	38.73***	-2.630	-3.963***

Notes: In the CD test: Under the null hypothesis of cross-section independence, CD ~ N(0,1), p-values close to zero indicate data are correlated across panel groups. In the CIPS test: H_0 (homogeneous non-stationary): $b_i = 0$ for all i, p-values close to zero indicate data are stationary.

[a]: Industry and agri is tested for the period 1997-2012 due to the availability of balanced panel.

[b]: Tested for the whole sample excluding Jordan due to the lack of data in the period 2010-2012.

[c]: We cannot test CIPS test for FDI due to the gaps in the dataset.

Table A8. Cointegration tests

Model	Kao test	Westerlund test	Pedroni test
	Dickey-Fuller t	Variance ratio	Phillips-Perron t
Model: f(**AE, Income, Agri**, **Energy**, **Trade**)	-7.912***	-4.084***	-8.744***
Model: f(**AE, Income, Agri**, **Energy**, **Trade, FDI**)	-3.853***	-2.618***	-8.495***
Model: f(**AE, Income, Agri**, **Energy**, **Export**)	-7.503***	-4.345***	-9.769***
Model: f(**AE, Income, Agri**, **Energy**, **Export, FDI**)	-3.641***	-2.718***	-9.009***
Model: f(**AE, Income, Agri**, **Energy**, **Import**)	-7.903***	-3.690***	-8.362***
Model: f(**AE, Income, Agri**, **Energy**, **Import, FDI**)	-3.696***	-2.239**	-7.937***
Model: f(**ME, Income, Agri**, **Energy**, **Trade**)	3.014***	-2.480***	-10.10***
Model: f(**ME, Income, Agri**, **Energy**, **Trade, FDI**)	7.916***	-0.829	-9.083***
Model: f(**ME, Income, Agri**, **Energy**, **Export**)	2.825***	-2.908***	-10.89***
Model: f(**ME, Income, Agri**, **Energy**, **Export, FDI**)	7.739***	-1.061	-8.810***
Model: f(**ME, Income, Agri**, **Energy**, **Import**)	3.269***	-2.060**	-9.560***
Model: f(**ME, Income, Agri**, **Energy**, **Import, FDI**)	8.049***	-0.657	-8.693***
Model: f(**NE, Income, Agri**, **Energy**, **Trade**)	1.667**	-3.512***	-14.74***
Model: f(**NE, Income, Agri**, **Energy**, **Trade, FDI**)	4.429***	-1.780**	-13.62***
Model: f(**NE, Income, Agri**, **Energy**, **Export**)	1.562*	-3.898***	-15.16***
Model: f(**NE, Income, Agri**, **Energy**, **Export, FDI**)	4.238***	-2.104**	-14.12***
Model: f(**NE, Income, Agri**, **Energy**, **Import**)	1.795**	-3.221***	-13.76***
Model: f(**NE, Income, Agri**, **Energy**, **Import, FDI**)	4.459***	-1.688**	-12.81***

Notes: In the Kao test for cointegration: H_0: No cointegration, Ha: All panels are cointegrated. In the Pedroni test for cointegration: H_0: No cointegration, Ha: All panels are cointegrated. In the Westerlund cointegration test: H_0: No cointegration, Ha: Some panels are cointegrated. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. n/a means the test cannot be performed. FIN is the financial development, proxied by nine indicators from FDI-IMF.

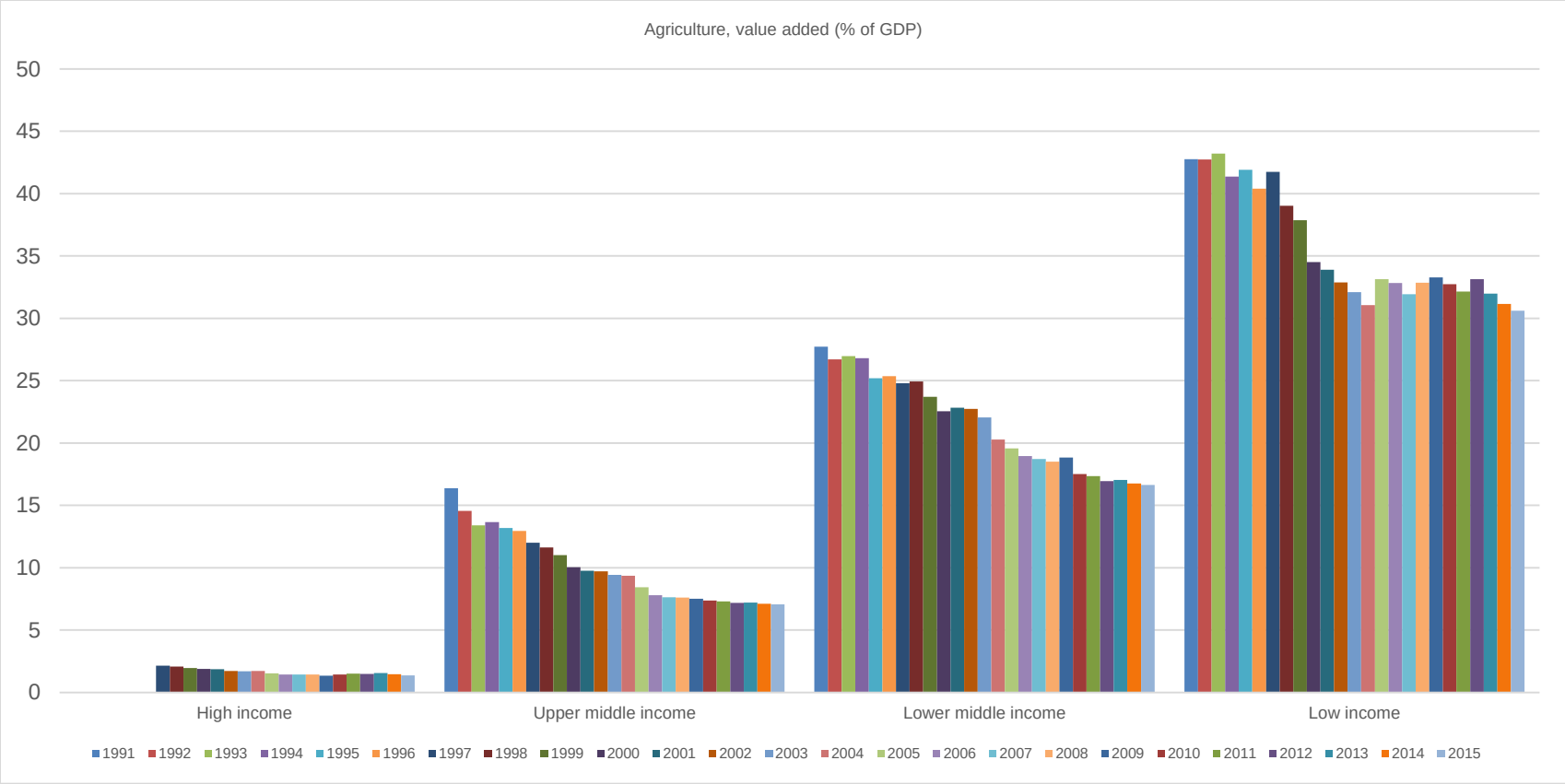

Figure A1. Agriculture value added to GDP (%).

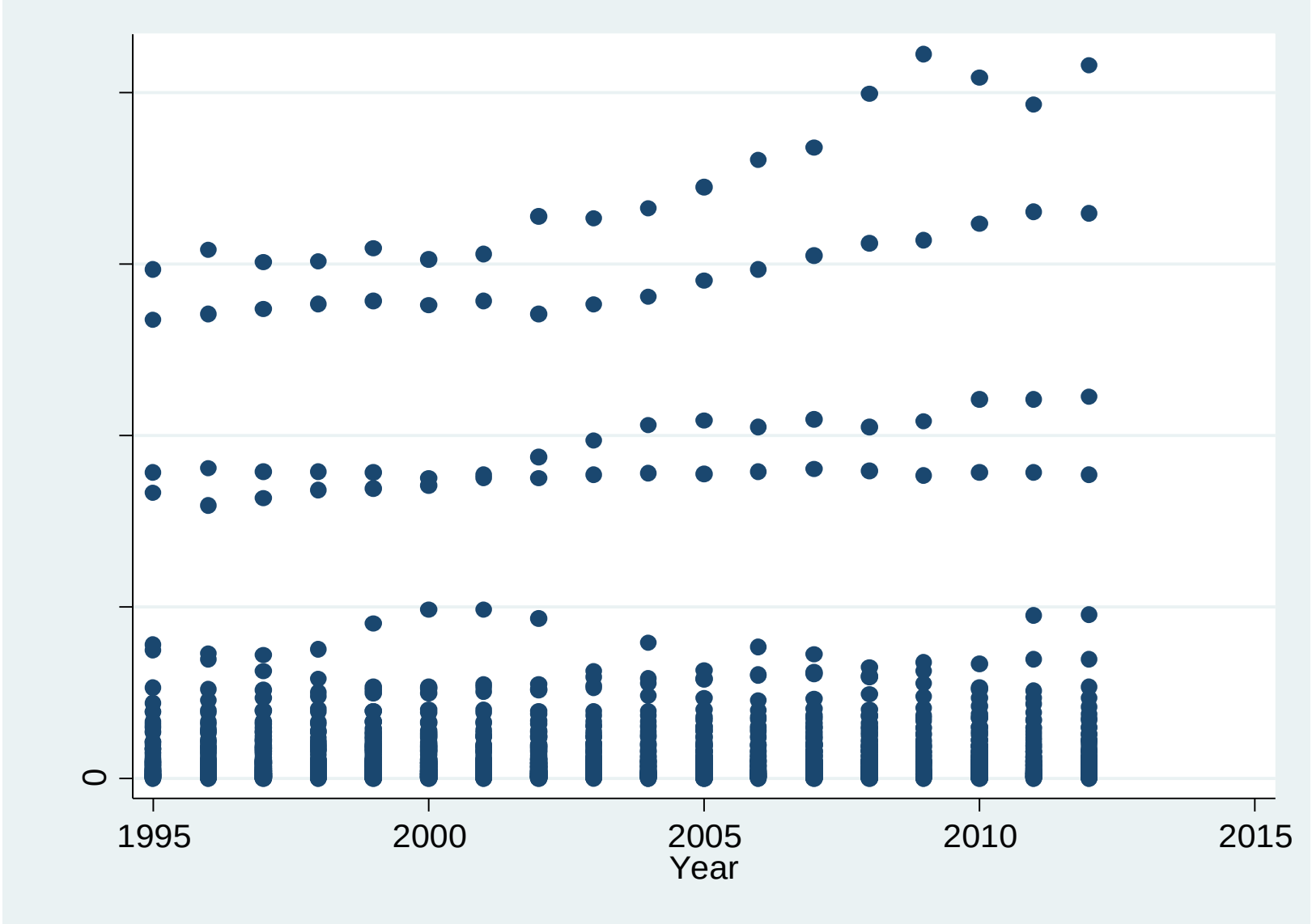

Figure A2. Total emissions from agriculture.

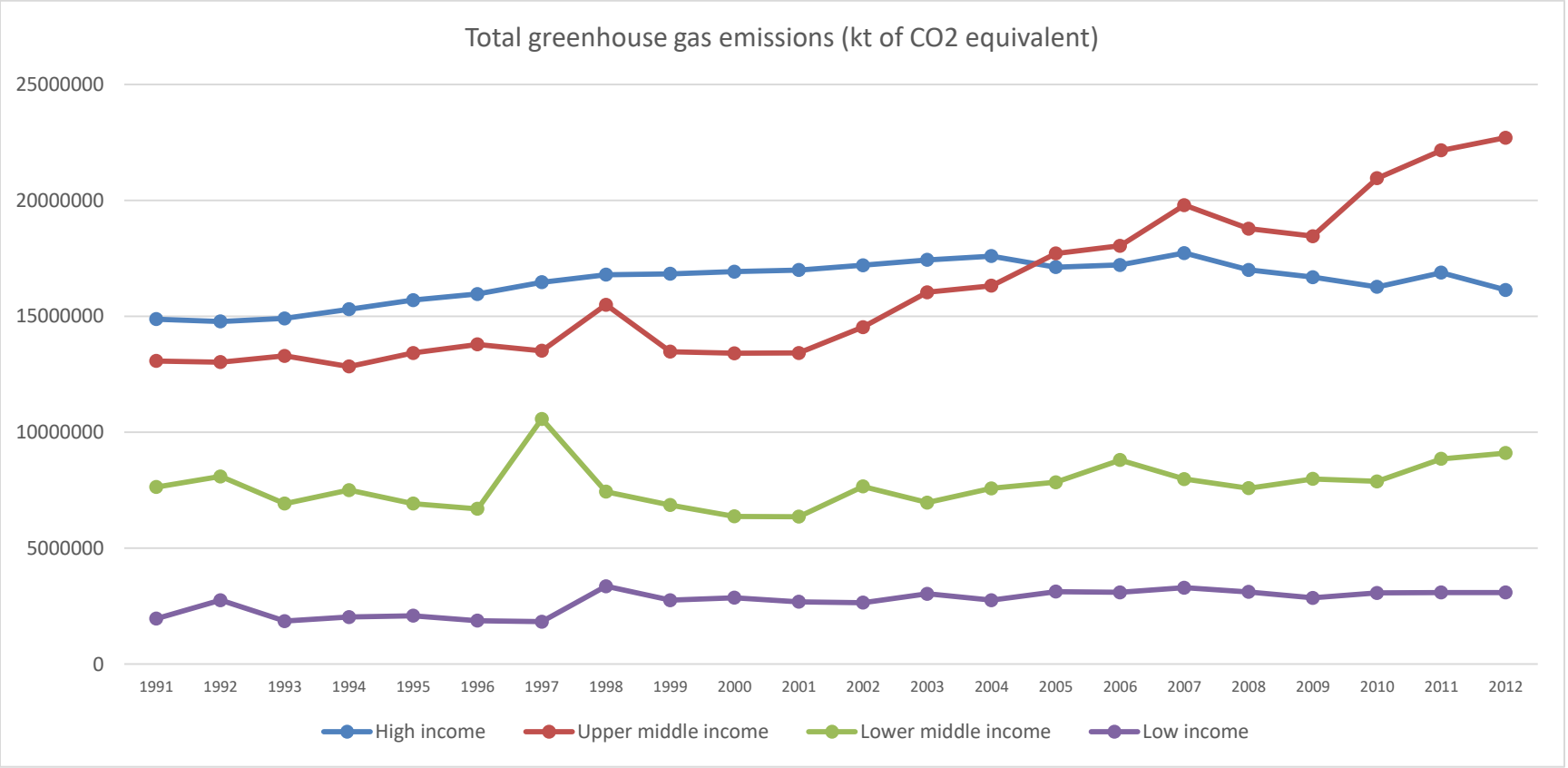

Figure A3. Total greenhouse gas emissions.

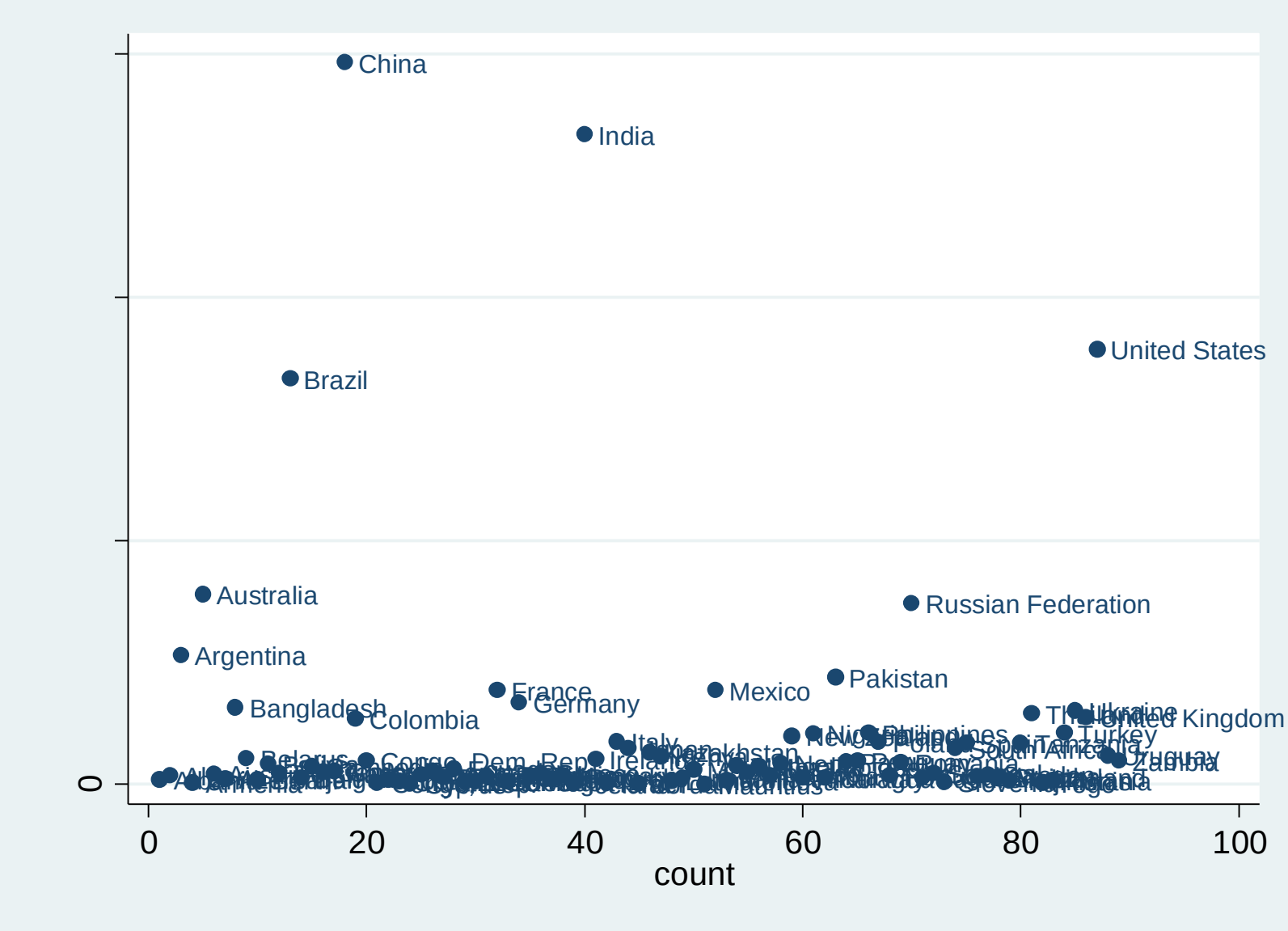

Figure A4. Total emissions by country in 1995.

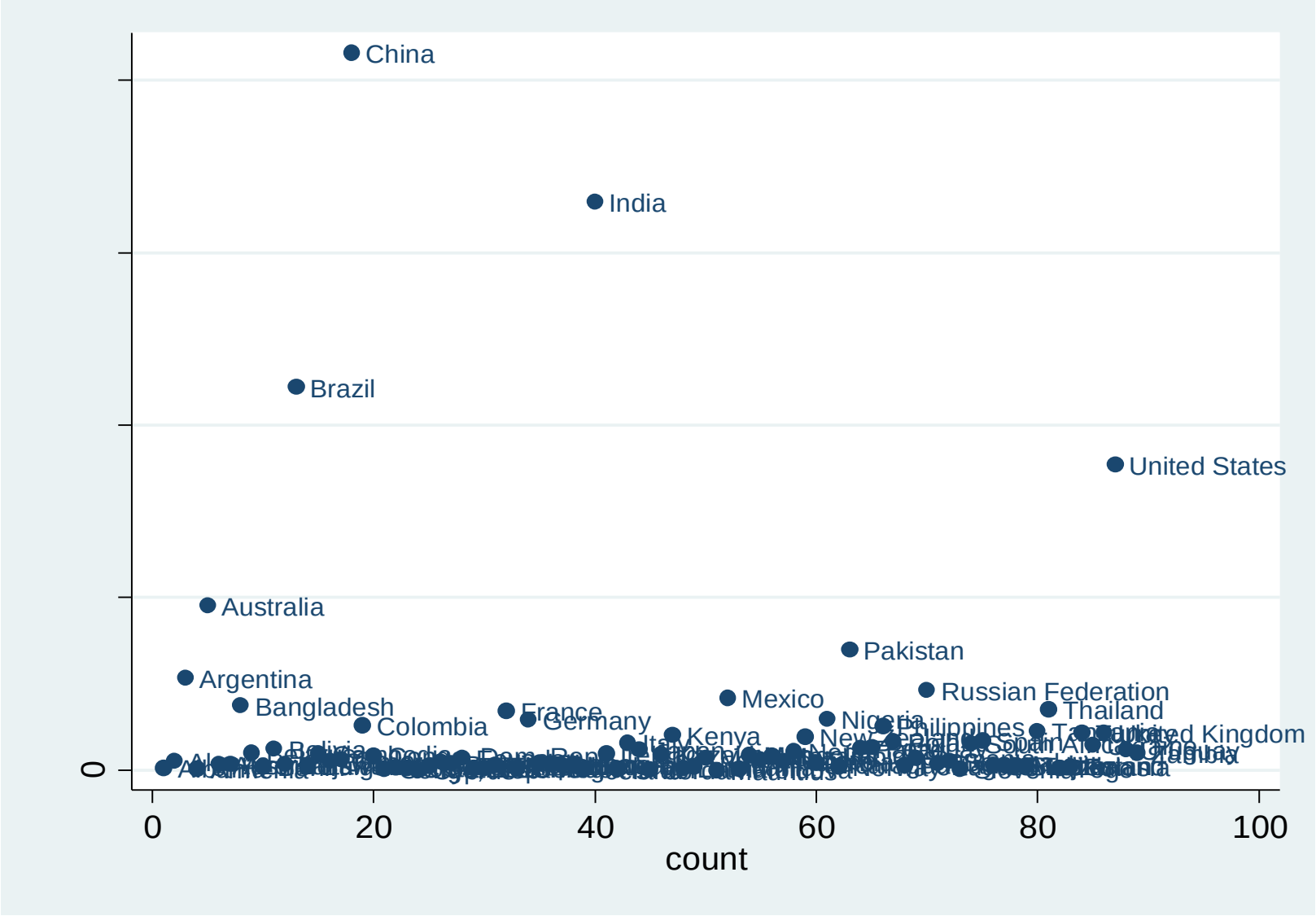

Figure A5. Total agricultural emissions by country in 2012.

Appendix B. Technical details of the ARDL model for panel data analysis in this study

The general ARDL model for panel data analysis is presented as follows:

$$Y_{it} = \alpha_{it} + \sum_{j=1}^{p_i} \beta_{ij} Y_{i,t-j} + \sum_{j=0}^{q_i} \delta_{ij} X1_{i,t-j} + \cdots + \sum_{j=0}^{k_i} \delta_{ij} Xk_{i,t-j} + \varepsilon_{it}. \quad \text{(A1)}$$

The ARDL model for equation (5) in the main text is transformed to equation (A1) as follows:

$$AE_{it} =$$
$$\alpha_{it} + \sum_{j=1}^{p_i} \beta_{ij} AE_{i,t-1} + \sum_{j=0,1}^{q_i} \delta_{ij} Income_{i,t-j} + \sum_{j=0,1}^{k_i} \theta_{ij} Agri_{i,t-j} +$$
$$\sum_{j=0,1}^{l_i} \gamma_{ij} Energy_{i,t-j} + \sum_{j=0,1}^{m_i} \sigma_{ij} Trade_{i,t-j} + \sum_{j=0,1}^{n_i} \tau_{ij} FDI_{i,t-j} + \varepsilon_{it}. \quad \text{(A2)}$$

As suggested by Pesaran *et al*. (1999), equation (A2) is re-parameterized into an error correction equation as follows:

$$\Delta AE_{it} = \alpha_{it} + \beta_i' AE_{i,t-1} + \delta_i' Income_{i,t} + \theta_i' Agri_{i,t} + \gamma_i' Energy_{i,t} + \sigma_i' Trade_{i,t} +$$
$$\tau_i' FDI_{i,t} + \sum_{j=1}^{p_{i-1}} \beta"_{ij} \Delta AE_{i,t-j} + \sum_{j=0}^{q_{i-1}} \delta"_{ij} \Delta Income_{i,t-j} + \sum_{j=0}^{k_{i-1}} \theta"_{ij} \Delta Agri_{i,t-j} +$$
$$\sum_{j=0}^{l_{i-1}} \gamma"_{ij} \Delta Energy_{i,t-j} + \sum_{j=0}^{m_{i-1}} \sigma"_{ij} \Delta Trade_{i,t-j} + \sum_{j=0}^{n_{i-1}} \tau"_{ij} \Delta FDI_{i,t-j} + \varepsilon_{it}\ , \quad \text{(A3)}$$

in which δ_i', θ_i', γ_i', σ_i', and τ_i' are long-run coefficients; and $\delta"_{ij}$, $\theta"_{ij}$, $\gamma"_{ij}$, $\sigma"_{ij}$, and $\tau"_{ij}$ are short-run coefficients, where

$$\delta_i' = -(1-\sum_{j=1}^{p_{i-1}} \beta"_{ij});\ \theta_i' = \sum_{j=0}^{q_i} \delta"_{ij};\ \gamma_i' = \sum_{j=0}^{l_i} \gamma"_{ij};\ \sigma_i' = \sum_{j=0}^{m_i} \sigma"_{ij};\ \tau_i' = \sum_{j=0}^{n_i} \tau"_{ij}\ .$$

Specifically, the long-run coefficients are the impacts of the explanatory variables (in levels) on the changes in the dependent variable (ΔAE), and the short-run coefficients are the

impacts of the changes in the corresponding explanatory variables on the change in the dependent variable (ΔAE).

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