

A real-options analysis of climate change and international migration

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ONLINE APPENDIX

Table A1. Specific emigration patterns: contiguity

	(1)	(2)
	Low-income countries	Middle-income countries
Smooth terms	<i>edf</i>	<i>edf</i>
s(T)	8.681*** (0.000)	8.727** (0.020)
s(T*contiguity)	1.085*** (0.002)	6.652 (0.892)
s(P)	8.860*** (0.000)	8.328*** (0.003)
s(P*contiguity)	6.681 (0.288)	6.560 (0.904)
REML score	-213916.7	-563102.4
AIC	-427922.9	-1126591
N	26520	81120
Pseudo-R ²	0.61	0.496

Note: Time period: 1990-2010. The dependent variable is the bilateral migration rate from country i to country j in five-year period t . $s(T)$ and $s(P)$ are smooth non-parametric functions of temperature and precipitation anomalies, respectively. Approximate p -values in parentheses. *edf*: effective degrees of freedom, REML: restricted maximum likelihood, AIC: Akaike information criterion. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A2. Specific emigration patterns: OECD destination countries

	(1)	(2)
	Low-income countries	Middle-income countries
Smooth terms	<i>edf</i>	<i>edf</i>
s(T)	8.383*** (0.000)	8.849*** (0.000)
s(T*OECD destination)	6.590*** (0.007)	8.752*** (0.000)
s(P)	8.911*** (0.000)	8.755*** (0.001)
s(P*OECD destination)	7.368 (0.327)	8.467*** (0.000)
REML score	-211100.2	-555241
AIC	-422273.9	-1110878
N	26520	81120
Pseudo-R ²	0.546	0.422

Note: Time period: 1990-2010. The dependent variable is the bilateral migration rate from country i to country j in five-year period t . $s(T)$ and $s(P)$ are smooth non-parametric functions of temperature and precipitation anomalies, respectively. Approximate p -values in parentheses. *edf*: effective degrees of freedom, REML: restricted maximum likelihood, AIC: Akaike information criterion. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A3. Robustness checks: alternative definitions of low-income country

	Bottom 20 %		Bottom 30 %	
	(1) Low-income countries <i>edf</i>	(2) Middle-income countries <i>edf</i>	(3) Low-income countries <i>edf</i>	(4) Middle-income countries <i>edf</i>
Smooth terms				
s(T)	8.370*** (0.000)	8.846*** (0.003)	8.688*** (0.000)	8.540*** (0.005)
s(P)	8.895*** (0.000)	8.160* (0.054)	8.836*** (0.000)	8.789*** (0.000)
REML score	-170233.6	-593466.5	-249564.1	-518850.3
AIC	-340471.2	-1187273	-499236.2	-1038020
N	21060	86580	31980	75660
Pseudo-R ²	0.563	0.400	0.538	0.438

Note: Time period: 1990-2010. The dependent variable is the bilateral migration rate from country i to country j in five-year period t . $s(T)$ and $s(P)$ are smooth non-parametric functions of temperature and precipitation anomalies, respectively. Approximate p -values in parentheses. *edf*: effective degrees of freedom, REML: restricted maximum likelihood, AIC: Akaike information criterion. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A4. Robustness checks: smoothing parameter selection using GCV

	(1)	(2)
	Low-income countries	Middle-income countries
Smooth terms	<i>edf</i>	<i>edf</i>
s(T)	8.712*** (0.000)	8.889*** (0.001)
s(P)	8.985*** (0.000)	8.704*** (0.001)
GCV score	5.492	6.033
AIC	-381587.4	-890441.9
N	26520	81120
Pseudo-R ²	0.544	0.416

Note: Time period: 1990-2010. The dependent variable is the bilateral migration rate from country i to country j in five-year period t . $s(T)$ and $s(P)$ are smooth non-parametric functions of temperature and precipitation anomalies, respectively. Approximate p -values in parentheses. *edf*: effective degrees of freedom, GCV: generalized cross validation, AIC: Akaike information criterion. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A5. Robustness checks: interacting climatic anomalies with quartiles of agricultural value added as a share of GDP

Smooth terms	Total sample <i>edf</i>
s(T*Q1)	8.597 (0.159)
s(T*Q2)	8.791*** (0.000)
s(T*Q3)	8.905*** (0.000)
s(T*Q4)	8.382*** (0.001)
s(P*Q1)	8.630 (0.158)
s(P*Q2)	8.814*** (0.000)
s(P*Q3)	8.907*** (0.000)
s(P*Q4)	7.917*** (0.000)
REML score	-705633.1
AIC	-1411848
N	99060
Pseudo-R ²	0.395

Note: Time period: 1990-2010. The dependent variable is the bilateral migration rate from country i to country j in five-year period t . $s(T)$ and $s(P)$ are smooth non-parametric functions of temperature and precipitation anomalies, respectively. Approximate p -values in parentheses. *edf*: effective degrees of freedom, REML: restricted maximum likelihood, AIC: Akaike information criterion. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A6. Robustness checks: including control variables

	(1)	(2)
	Low-income countries	Middle-income countries
Parametric terms	Estimate	Estimate
ln(GDP per capita ratio)	-0.040 (0.062)	0.156*** (0.043)
Common language	0.828*** (0.078)	1.041*** (0.048)
ln(Distance)	-3.028*** (0.041)	-1.960*** (0.021)
Civil war	0.072*** (0.028)	0.171*** (0.025)
Smooth terms	<i>edf</i>	<i>edf</i>
s(T)	8.438*** (0.000)	6.697** (0.039)
s(P)	8.589** (0.023)	8.558*** (0.002)
REML score	-191498.8	-519325.9
AIC	-383137.8	-1039129
N	23331	72114
Pseudo-R ²	0.709	0.691

Note: Time period: 1990-2010. The dependent variable is the bilateral migration rate from country i to country j in five-year period t . $s(T)$ and $s(P)$ are smooth non-parametric functions of temperature and precipitation anomalies, respectively. For parametric estimates, standard errors are reported in parentheses, while for smooth terms approximate p -values are reported in parentheses. *edf*: effective degrees of freedom, REML: restricted maximum likelihood, AIC: Akaike information criterion. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A7. Robustness checks: using five-year period shares of heat and drought months

	(1)	(2)
	Low-income countries	Middle-income countries
Smooth terms	<i>edf</i>	<i>edf</i>
s(Heat month share)	8.608*** (0.000)	8.812*** (0.000)
s(Drought month share)	8.884*** (0.000)	7.702* (0.069)
REML score	-211233.9	-554707.2
AIC	-422517.6	-1109729
N	26520	81120
Pseudo-R ²	0.548	0.416

Note: Time period: 1990-2010. The dependent variable is the bilateral migration rate from country i to country j in five-year period t . s (Heat month share) and s (Drought month share) are smooth non-parametric functions of five-year period heat and drought month shares, respectively. Approximate p -values in parentheses. *edf*: effective degrees of freedom, REML: restricted maximum likelihood, AIC: Akaike information criterion. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A8. Robustness checks: excluding extreme outliers

	(1)	(2)
Smooth terms	Low-income countries	Middle-income countries
	<i>edf</i>	<i>edf</i>
s(T)	8.647*** (0.000)	8.750** (0.012)
s(P)	8.770*** (0.000)	8.802*** (0.001)
REML score	-192912.9	-531276.5
AIC	-385852.6	-1062869
N	24375	77025
Pseudo-R ²	0.537	0.42

Note: Time period: 1990-2010. The dependent variable is the bilateral migration rate from country i to country j in five-year period t . $s(T)$ and $s(P)$ are smooth non-parametric functions of temperature and precipitation anomalies, respectively. Approximate p -values in parentheses. *edf*: effective degrees of freedom, REML: restricted maximum likelihood, AIC: Akaike information criterion. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

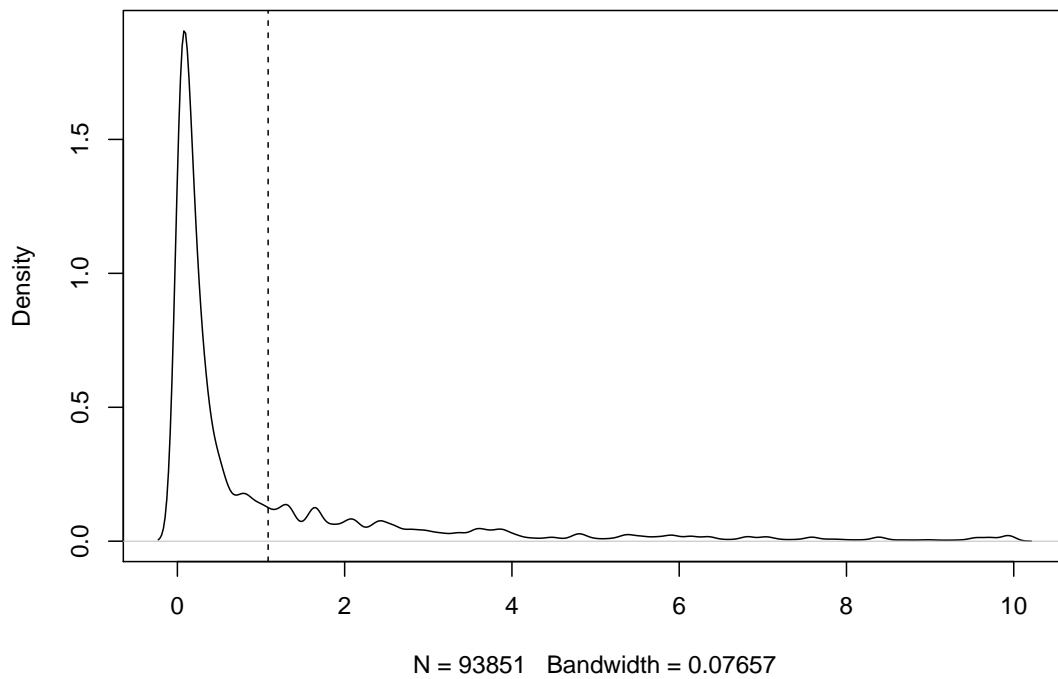
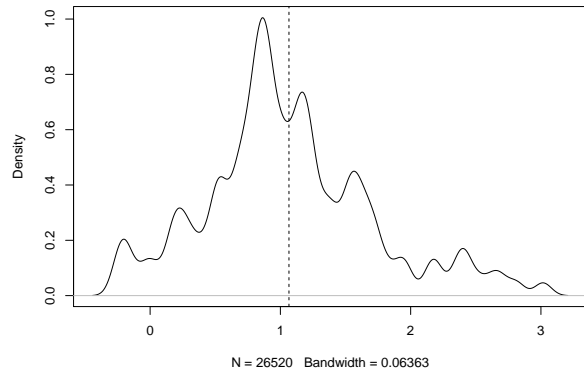
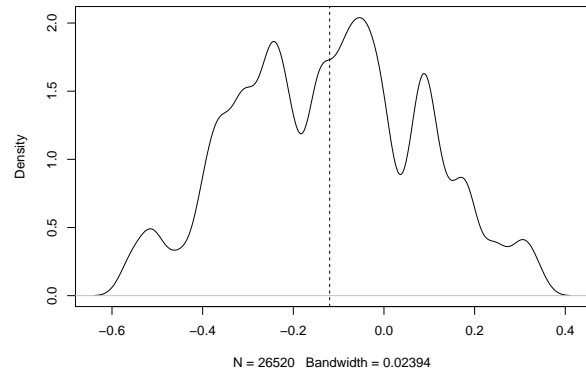


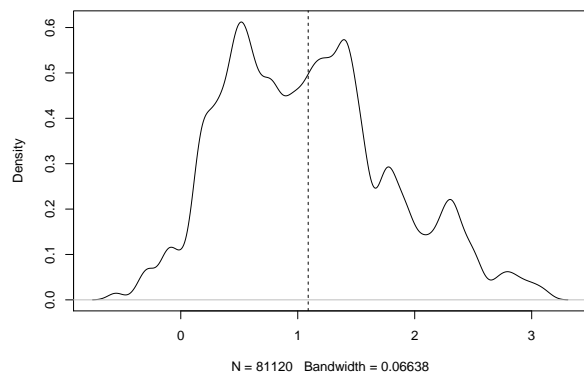
Figure A1. Kernel density estimation of bilateral migration rates. Only for the purpose of the kernel density estimation, we have scaled bilateral migration rates by a factor of 10^6 and excluded observations greater than 10.



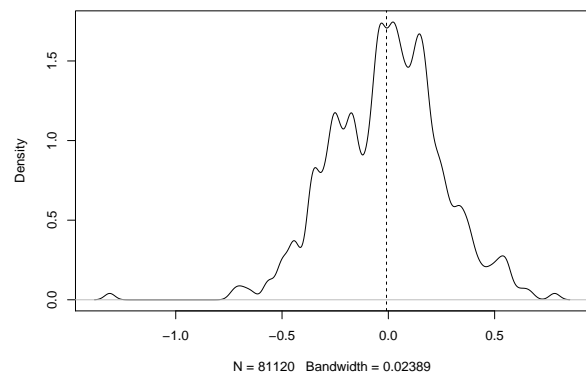
(a) Temperature, low-income countries



(b) Precipitation, low-income countries

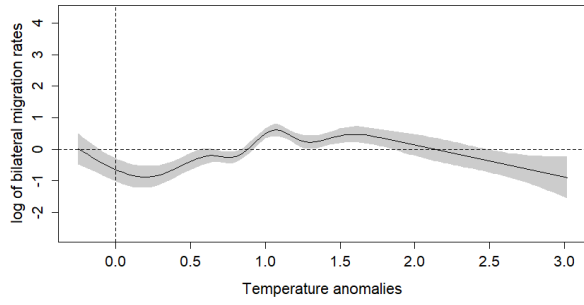


(c) Temperature, middle-income countries

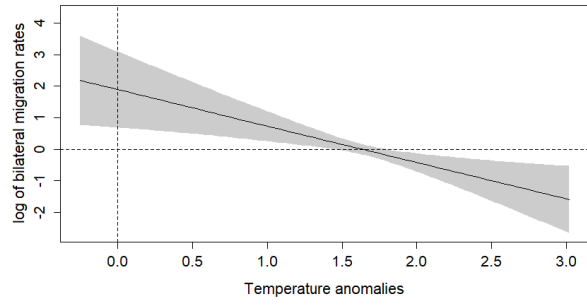


(d) Precipitation, middle-income countries

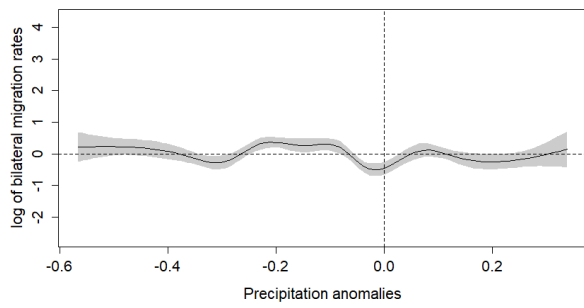
Figure A2. Kernel density estimations of temperature and precipitation anomalies for low- and middle-income countries.



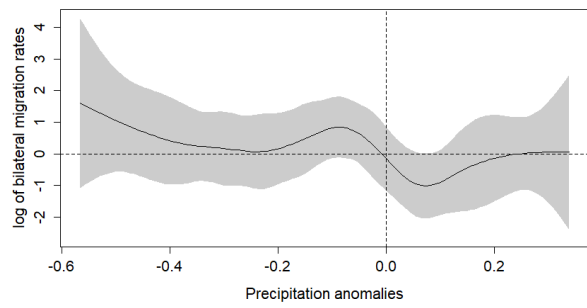
(a) Temperature and migration to nonneighboring countries



(b) Temperature and migration to neighboring countries

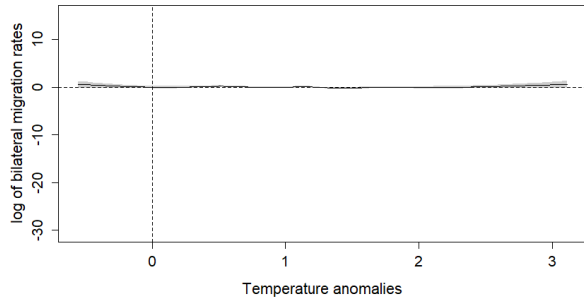


(c) Precipitation and migration to nonneighboring countries

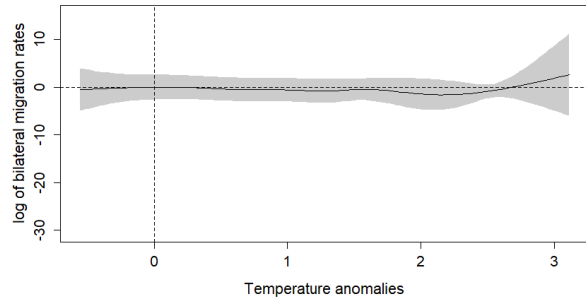


(d) Precipitation and migration to neighboring countries

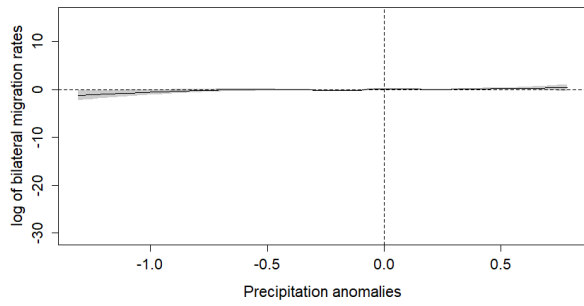
Figure A3. Nonlinear effects of temperature and precipitation anomalies on migration from low-income countries to neighboring and nonneighboring countries.



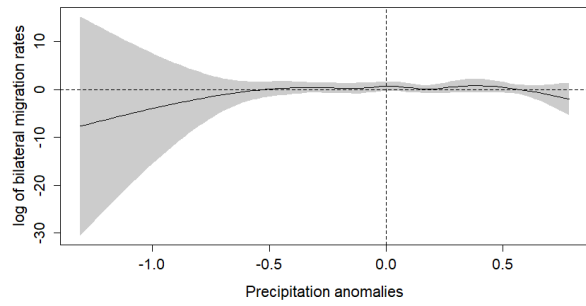
(a) Temperature and migration to nonneighboring countries



(b) Temperature and migration to neighboring countries

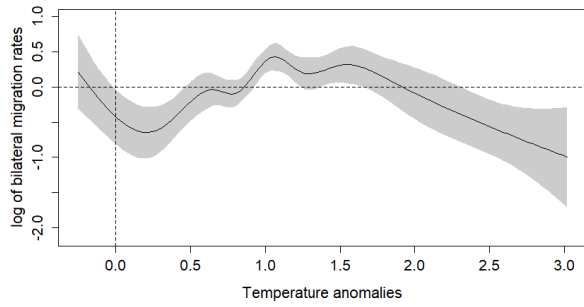


(c) Precipitation and migration to nonneighboring countries

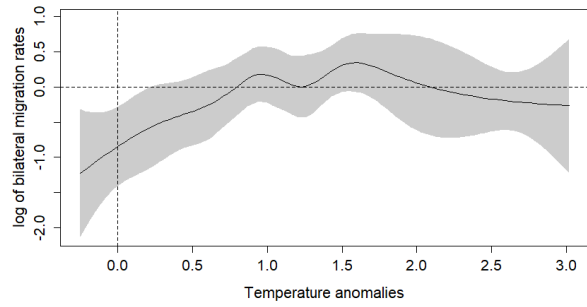


(d) Precipitation and migration to neighboring countries

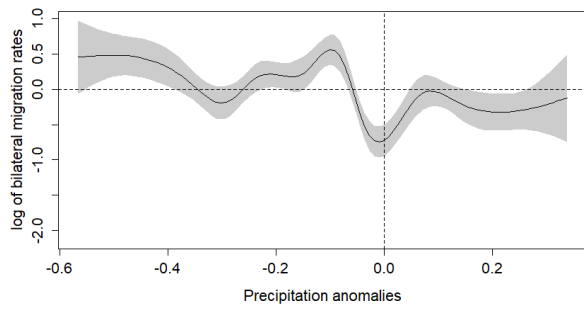
Figure A4. Nonlinear effects of temperature and precipitation anomalies on migration from middle-income countries to neighboring and nonneighboring countries.



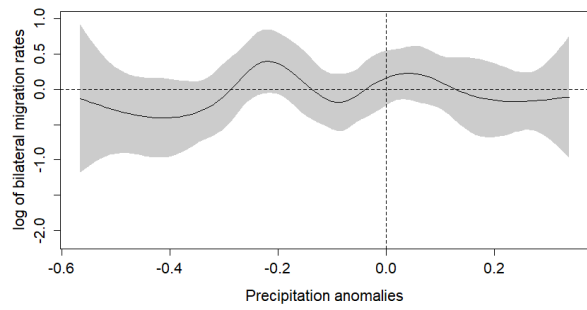
(a) Temperature and migration to non-OECD countries



(b) Temperature and migration to OECD countries

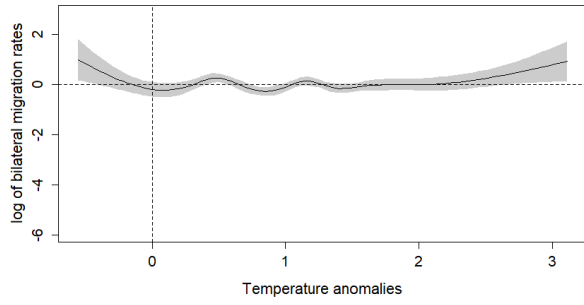


(c) Precipitation and migration to non-OECD countries

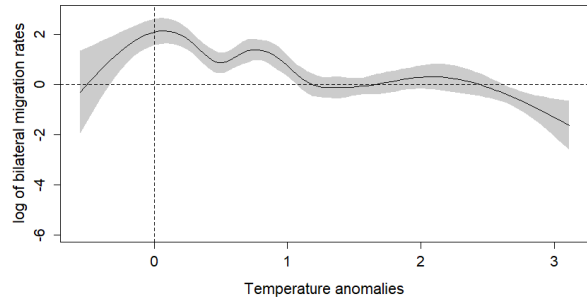


(d) Precipitation and migration to OECD countries

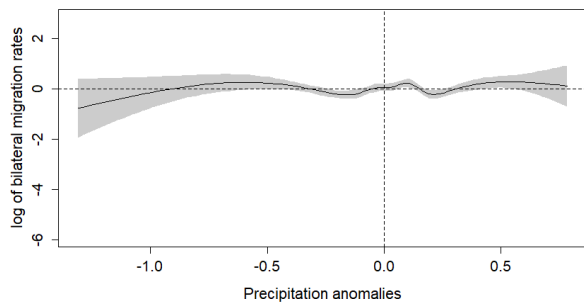
Figure A5. Nonlinear effects of temperature and precipitation anomalies on migration from low-income countries to OECD and non-OECD countries.



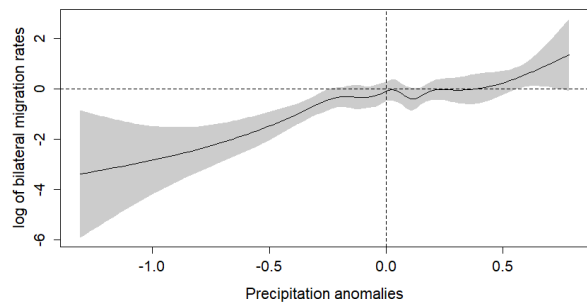
(a) Temperature and migration to non-OECD countries



(b) Temperature and migration to OECD countries

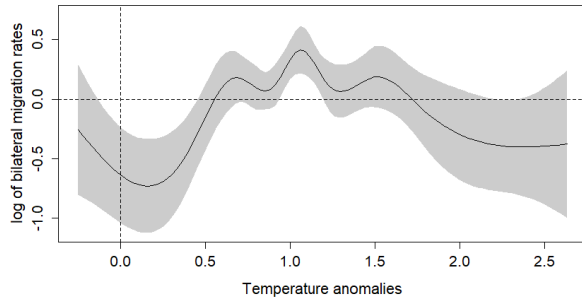


(c) Precipitation and migration to non-OECD countries

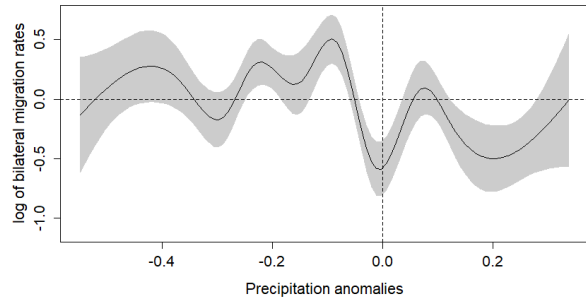


(d) Precipitation and migration to OECD countries

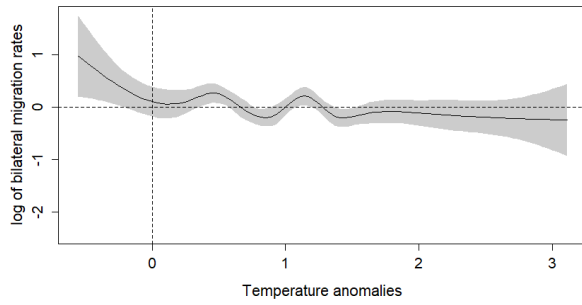
Figure A6. Nonlinear effects of temperature and precipitation anomalies on migration from middle-income countries to OECD and non-OECD countries.



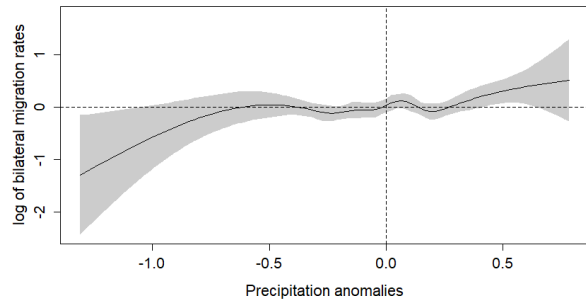
(a) Temperature, low-income countries



(b) Precipitation, low-income countries

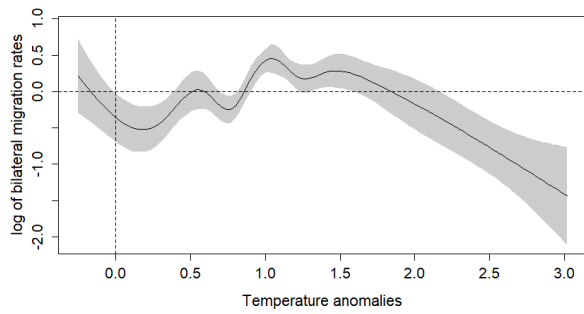


(c) Temperature, middle-income countries

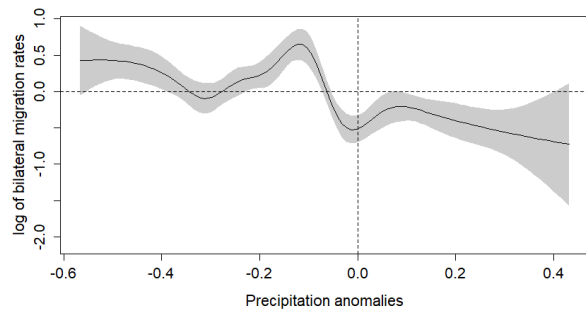


(d) Precipitation, middle-income countries

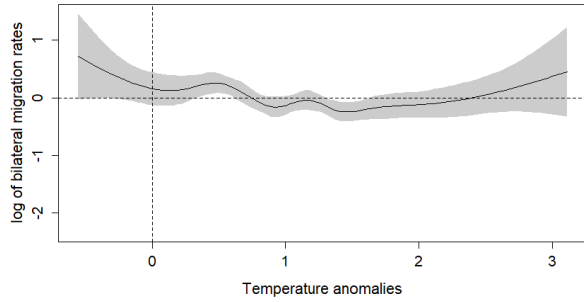
Figure A7. Nonlinear effects of temperature and precipitation anomalies on migration: defining the bottom 20% of the income distribution as low-income countries.



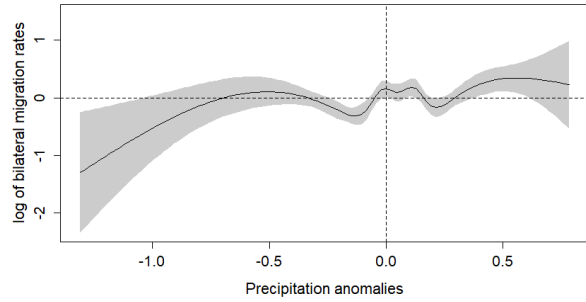
(a) Temperature, low-income countries



(b) Precipitation, low-income countries

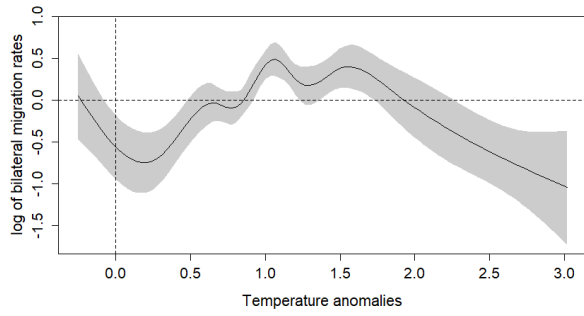


(c) Temperature, middle-income countries

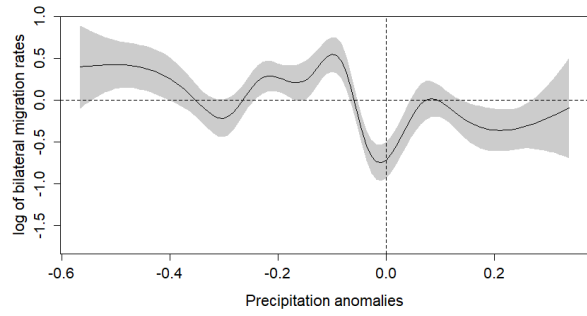


(d) Precipitation, middle-income countries

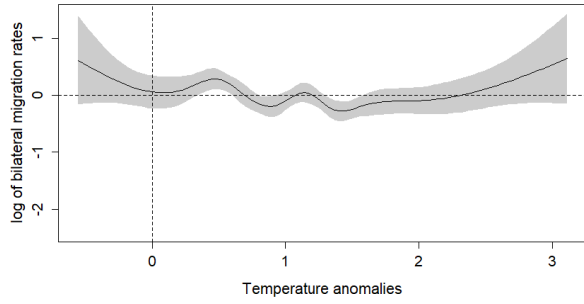
Figure A8. Nonlinear effects of temperature and precipitation anomalies on migration: defining the bottom 30% of the income distribution as low-income countries.



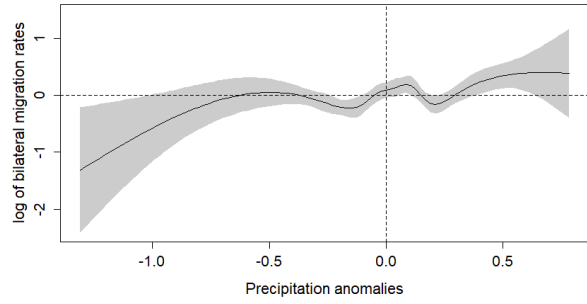
(a) Temperature, low-income countries



(b) Precipitation, low-income countries

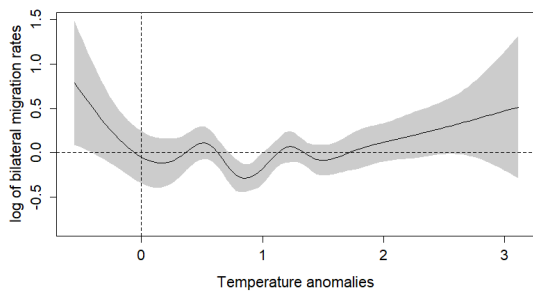


(c) Temperature, middle-income countries

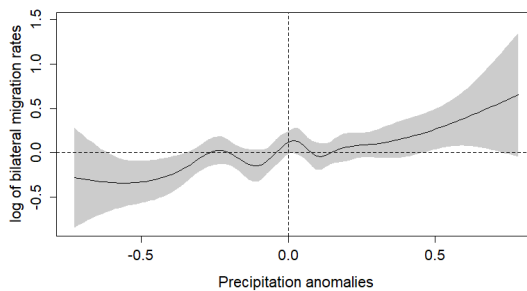


(d) Precipitation, middle-income countries

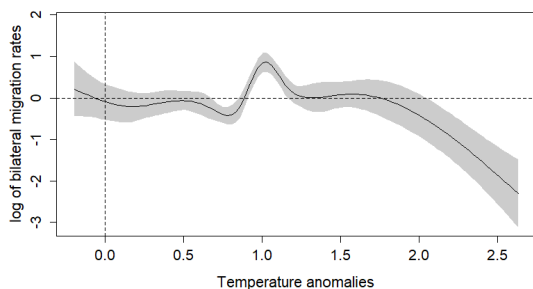
Figure A9. Nonlinear effects of temperature and precipitation anomalies on migration: smoothing parameter selection using GCV.



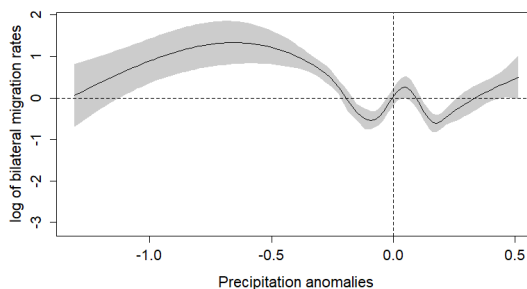
(a) Temperature, quartile 1



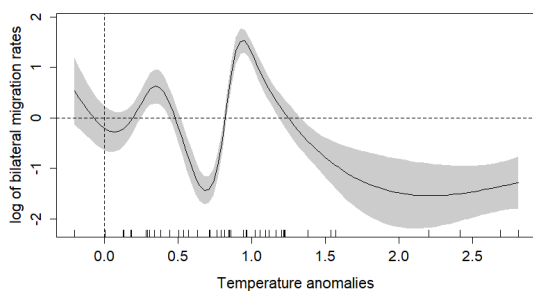
(b) Precipitation, quartile 1



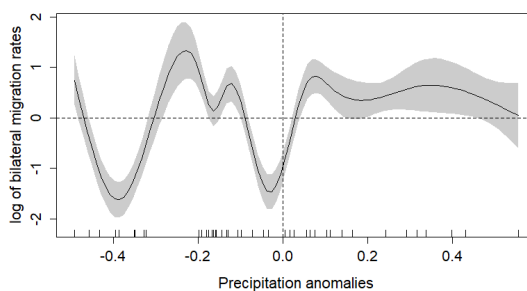
(c) Temperature, quartile 2



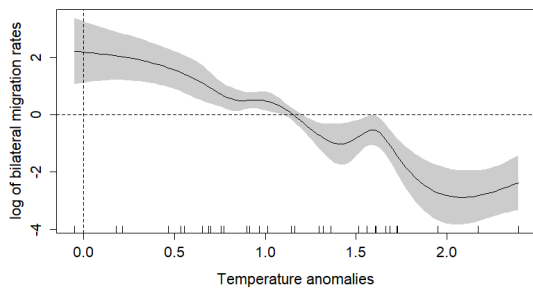
(d) Precipitation, quartile 2



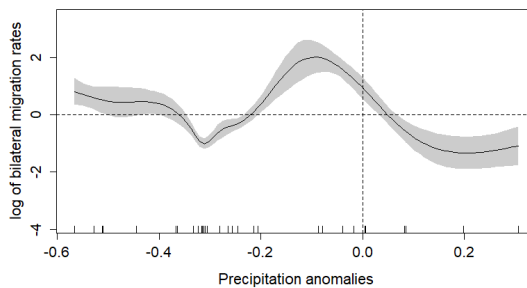
(e) Temperature, quartile 3



(f) Precipitation, quartile 3

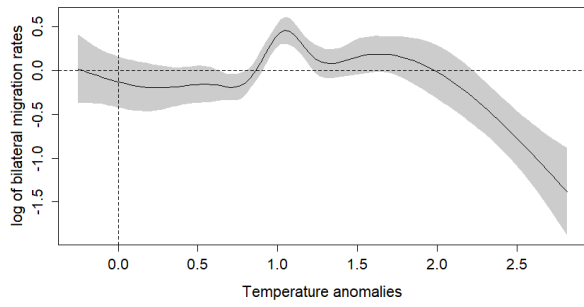


(g) Temperature, quartile 4

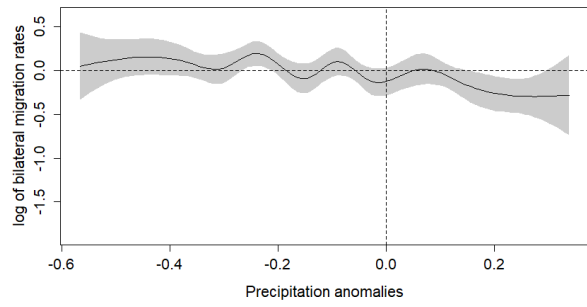


(h) Precipitation, quartile 4

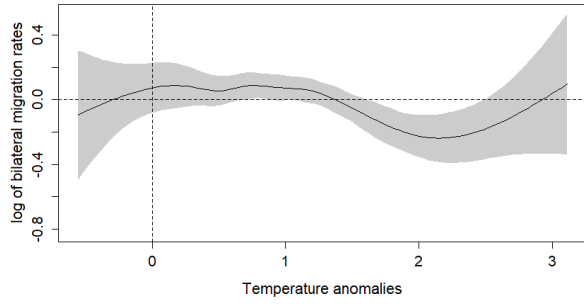
Figure A10. Nonlinear effects of temperature and precipitation anomalies on migration: interacting climatic anomalies with quartiles of agricultural value added as a share of GDP.



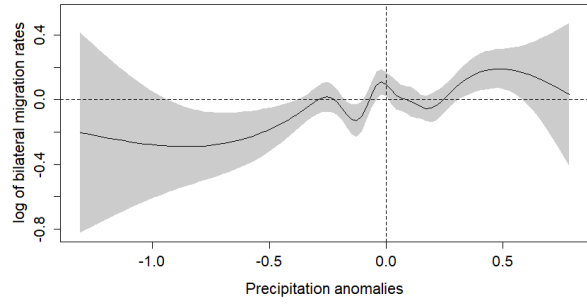
(a) Temperature, low-income countries



(b) Precipitation, low-income countries

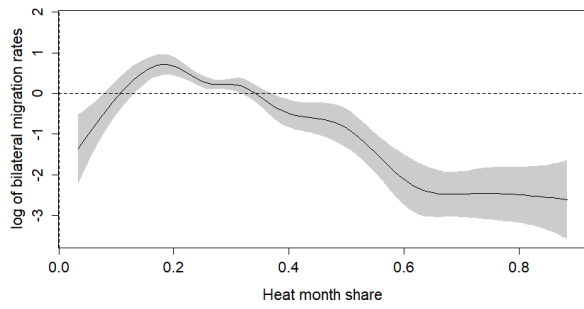


(c) Temperature, middle-income countries

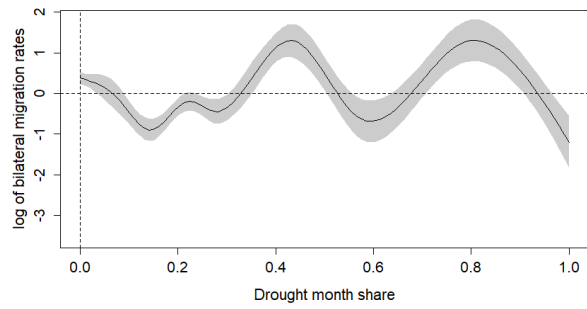


(d) Precipitation, middle-income countries

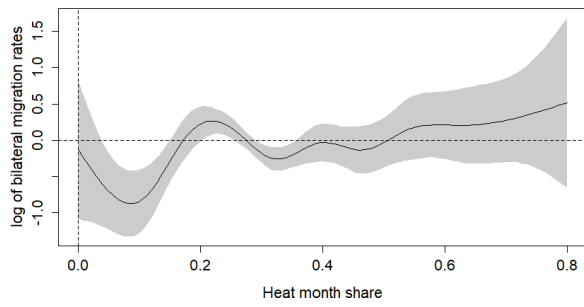
Figure A11. Nonlinear effects of temperature and precipitation anomalies on migration: including control variables.



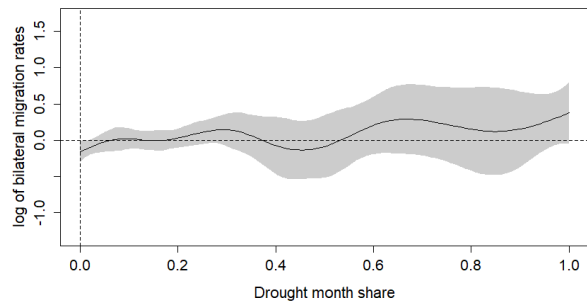
(a) Heat month share, low-income countries



(b) Drought month share, low-income countries

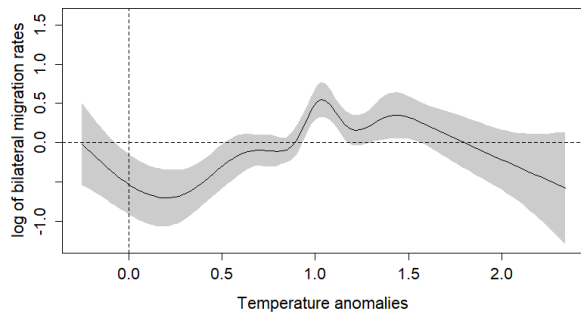


(c) Heat month share, middle-income countries

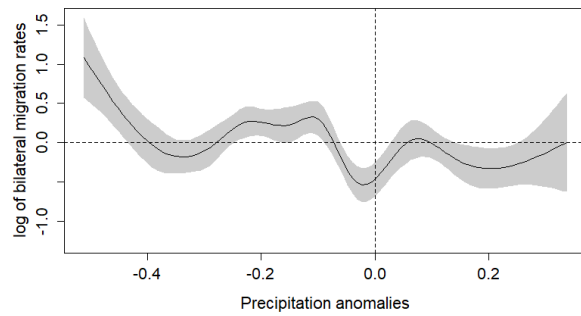


(d) Drought month share, middle-income countries

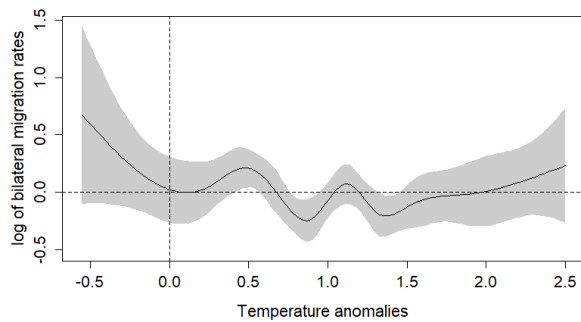
Figure A12. Nonlinear effects of temperature and precipitation anomalies on migration: using five-year period shares of heat and drought months.



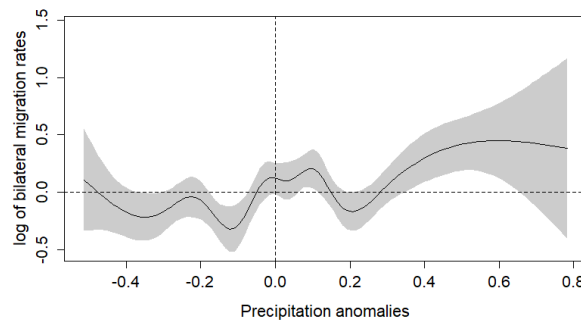
(a) Temperature, low-income countries



(b) Precipitation, low-income countries



(c) Temperature, middle-income countries



(d) Precipitation, middle-income countries

Figure A13. Nonlinear effects of temperature and precipitation anomalies on migration: excluding extreme outliers.

List of low-income countries

Bangladesh, Bosnia-Herzegovina, Burkina Faso, Burundi, Cambodia, Cape Verde, Central African Republic, Chad, China, Democratic Republic of Congo, Equatorial Guinea, Ethiopia, Guinea, India, Lesotho, Liberia, Madagascar, Malawi, Mali, Mozambique, Myanmar, Nepal, Niger, Rwanda, Sao Tome and Principe, Sierra Leone, South Sudan, Sudan, Syria, Tanzania, Togo, Uganda, Vietnam, Yemen

List of middle-income countries

Albania, Algeria, Angola, Argentina, Armenia, Azerbaijan, Bahamas, Bahrain, Barbados, Belarus, Belize, Benin, Bhutan, Bolivia, Botswana, Brazil, Brunei, Bulgaria, Cameroon, Comoros, Costa Rica, Croatia, Cyprus, Djibouti, Dominican Republic, Ecuador, Egypt, El Salvador, Fiji, Gabon, Gambia, Georgia, Ghana, Grenada, Guatemala, Guinea Bissau, Guyana, Haiti, Honduras, Hong Kong, Indonesia, Iran, Iraq, Ivory Coast, Jamaica, Jordan, Kazakhstan, Kenya, Kuwait, Kyrgyzstan, Laos, Lebanon, Libya, Macao, Macedonia, Malaysia, Maldives, Malta, Mauritania, Mauritius, Moldova, Mongolia, Montenegro, Morocco, Namibia, Nicaragua, Nigeria, Oman, Pakistan, Panama, Papua New-Guinea, Paraguay, Peru, Philippines, Puerto Rico, Qatar, Republic of Congo, Romania, Russia, Samoa, Saudi Arabia, Senegal, Serbia, Singapore, Solomon Islands, South Africa, South Korea, Sri Lanka, Suriname, Swaziland, Tajikistan, Thailand, Tonga, Trinidad and Tobago, Tunisia, Turkmenistan, Ukraine, United Arab Emirates, Uruguay, Uzbekistan, Vanuatu, Venezuela, Zambia, Zimbabwe