

# The Coexistence of Infection Spread Patterns in the Global Dynamics of COVID-19 Dissemination

## Supplementary Information

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### 1 Supplementary figures

The following is the list of figures referred to in the main text.

SI Figure 1: Number of infected cases in all countries. In the main text, only the 20 most populous countries are shown for improved visibility.

SI Figure 2: Log ratio of infected cases in all countries. In the main text, only the 20 most populous countries are shown for improved visibility.

SI Figure 3: The legends for SI Figures 1 and 2.

SI Figure 4: Pair plots between auxiliary data points.

SI Figure 5: Scree plots for each year. In the main text, the scree plot for the entire period is shown.

SI Figure 6: The first eigenvectors for the entire period, 2020, 2021, and 2022. The plots are coloured by region. The axes represent the argument and the ordinate.

SI Figure 7: The first eigenvectors for the entire period, 2020, 2021, and 2022. The plots are coloured by region. The figure shown on the complex plane corresponds to SI Figure 6 in the main text.

SI Figure 8: The first eigenvectors for the entire period, 2020, 2021, and 2022. The plots are coloured according to population. The axes represent the argument and the ordinate.

SI Figure 9: The first eigenvectors for the entire period, 2020, 2021, and 2022. The plots are coloured according to GDP per capita. The axes represent the argument and the ordinate.

SI Figure 10: Barycentres for each of five GDP per capita group based on rank. The panels show the entire period, 2020, 2021, and 2022. This figure corresponds to SI Figure 9.

SI Figure 11: The first eigenvectors for the entire period, 2020, 2021, and 2022. The plots are coloured according to the stringency index [2]. The axes represent the argument and the ordinate.

SI Figure 12: Barycentres for each of five stringency index group based on rank. The panels show the entire period, 2020, 2021, and 2022. This figure corresponds to SI Figure 11.

SI Figure 13: The first eigenvectors for the entire period, 2020, 2021, and 2022. The plots are coloured according to the containment and health index [2]. The axes represent the argument and the ordinate.

SI Figure 14: Barycentres for each of five containment and health index groups based on rank. The panels show the entire period, 2020, 2021, and 2022. This figure corresponds to SI Figure 13.

SI Figure 15: The first eigenvectors for the entire period, 2020, 2021, and 2022. The plots are coloured according to the vaccination rate. The axes represent the argument and the ordinate.

SI Figure 16: Barycentres for each of five vaccination rate groups based on rank. The panels show the entire period, 2020, 2021, and 2022. This figure corresponds to SI Figure 15.

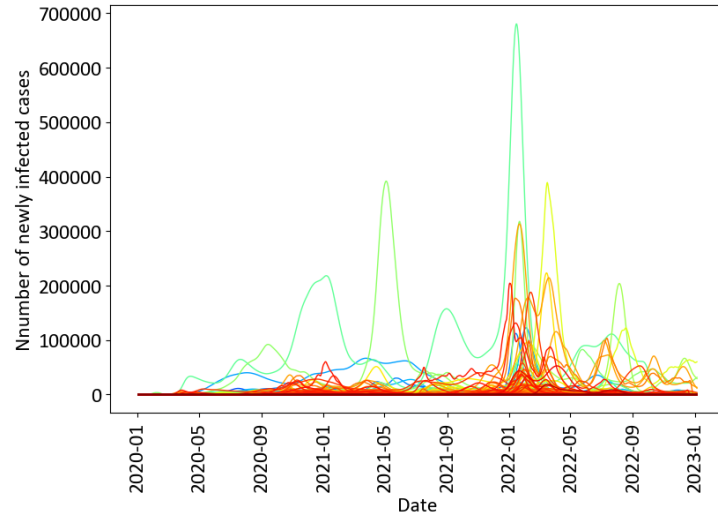
SI Figure 17: The first eigenvectors for the entire period, 2020, 2021, and 2022. The plots are coloured according to the democracy index. The figure shown on the complex plane corresponds to Figure 5 in the main text.

SI Figure 18: The second eigenvectors for the entire period data. The panels are coloured by region, population, stringency index, and democracy index.

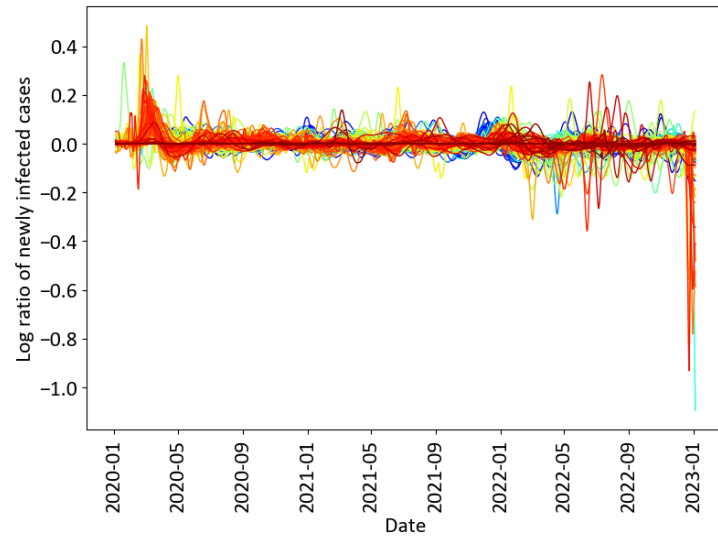
SI Figure 20: The second eigenvectors for the 2020 data. The panels are coloured by region, population, stringency index, and democracy index.

SI Figure 22: The second eigenvectors for the 2021 data. The panels are coloured by region, population, stringency index, and democracy index.

SI Figure 24: The second eigenvectors for the 2022 data. The panels are coloured by region, population, stringency index, and democracy index.



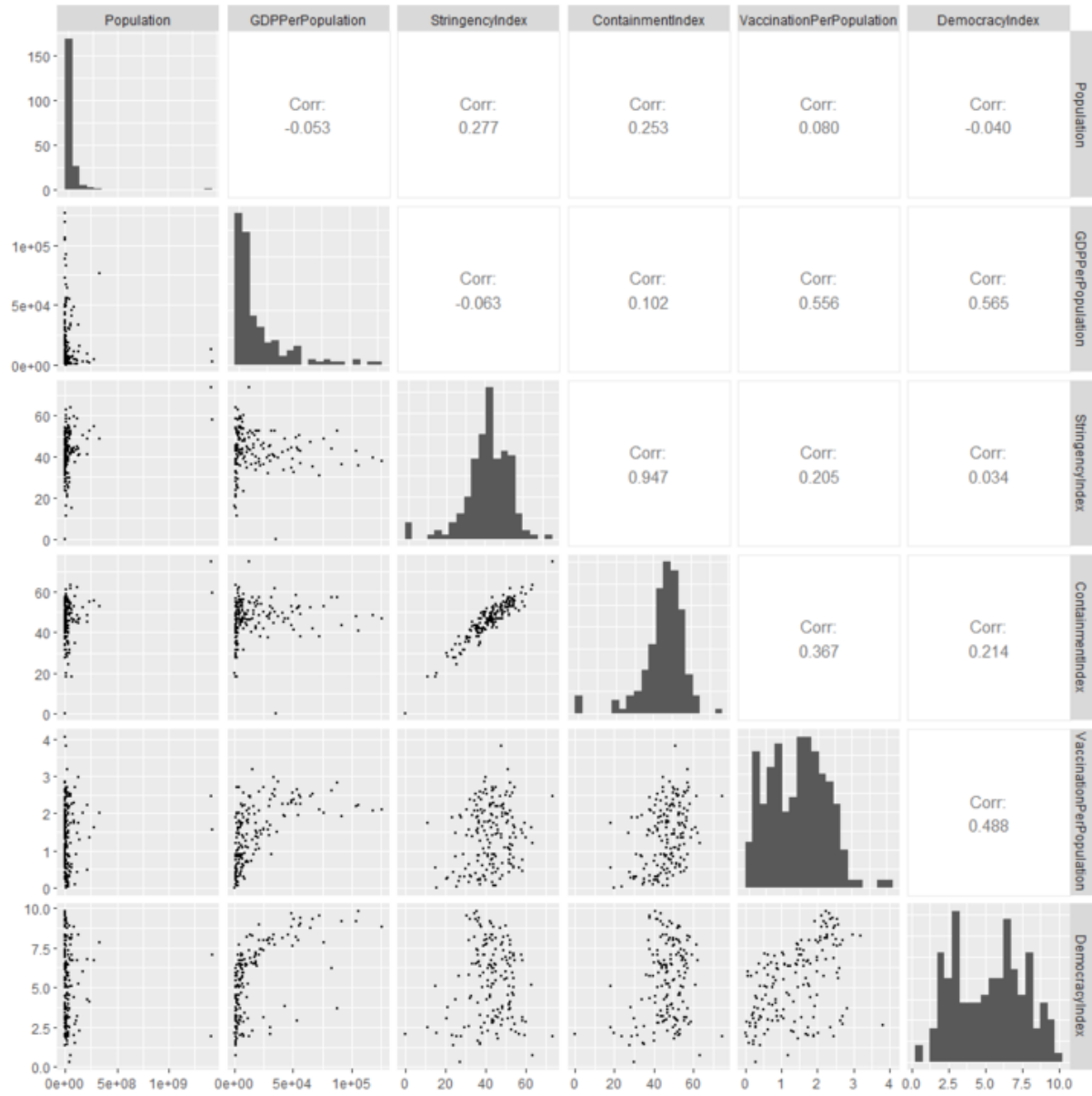
SI Figure 1: Number of infected cases in all countries. Each colour indicates a country. The correspondence of the colours with the countries is shown in SI Figure 3.



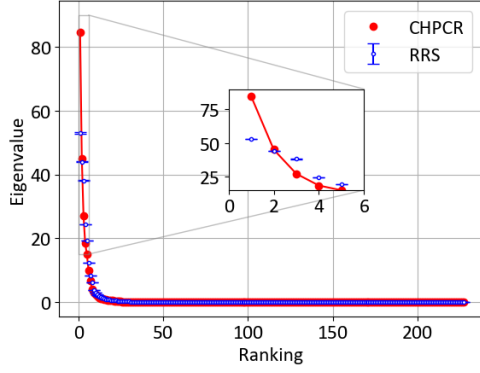
SI Figure 2: Log ratio of infected cases for all countries. Each colour indicates a country. The correspondence of the colours with the countries is shown in SI Figure 3.

Country			
Algeria	Antigua and Barbuda	Bhutan	Greece
Angola	Argentina	Brunei Darussalam	Guernsey
Benin	Aruba	Cambodia	Holy See
Burkina Faso	Bahamas	China	Hungary
Burundi	Barbados	Cyprus	Iceland
Cabo Verde	Bermuda	Georgia	Ireland
Cameroon	Bolivia	India	Isle of Man
Central African Republic	Bonaire	Indonesia	Italy
Chad	Brazil	Iran	Jersey
Comoros	British Virgin Islands	Iraq	Latvia
Congo	Canada	Israel	Liechtenstein
Côte d'Ivoire	Cayman Islands	Japan	Lithuania
Democratic Republic of the Congo	Chile	Jordan	Luxembourg
Djibouti	Colombia	Kazakhstan	Malta
Egypt	Costa Rica	Kuwait	Monaco
Equatorial Guinea	Cuba	Kyrgyzstan	Montenegro
Eritrea	Curaçao	Lao People's Democratic Republic	Netherlands
Eswatini	Dominica	Lebanon	North Macedonia
Ethiopia	Dominican Republic	Malaysia	Norway
Gabon	Ecuador	Maldives	Poland
Gambia	El Salvador	Mongolia	Portugal
Ghana	Falkland Islands	Myanmar	Republic of Moldova
Guinea	French Guiana	Nepal	Romania
Guinea Bissau	Greenland	Oman	Russian Federation
Kenya	Grenada	Pakistan	San Marino
Lesotho	Guadeloupe	Palestine	Serbia
Liberia	Guatemala	Philippines	Slovakia
Libya	Guyana	Qatar	Slovenia
Madagascar	Haiti	Republic of Korea	Spain
Malawi	Honduras	Saudi Arabia	Sweden
Mali	Jamaica	Singapore	Switzerland
Mauritania	Martinique	Sri Lanka	The United Kingdom
Mauritius	Mexico	Syrian Arab Republic	Ukraine
Mayotte	Montserrat	Tajikistan	American Samoa
Morocco	Nicaragua	Thailand	Australia
Mozambique	Panama	Timor Leste	Cook Islands
Namibia	Paraguay	Turkey	Fiji
Niger	Peru	United Arab Emirates	French Polynesia
Nigeria	Puerto Rico	Uzbekistan	Guam
Rwanda	Saint Barthélemy	Viet Nam	Kiribati
Réunion	Saint Kitts and Nevis	Yemen	Marshall Islands
Saint Helena	Saint Lucia	Albania	Micronesia
Sao Tome and Principe	Saint Pierre and Miquelon	Andorra	Nauru
Senegal	Saint Vincent and the Grenadines	Austria	New Caledonia
Seychelles	Sint Maarten	Belarus	New Zealand
Sierra Leone	Suriname	Belgium	Niue
Somalia	Trinidad and Tobago	Bosnia and Herzegovina	Northern Mariana Islands
South Africa	Turks and Caicos Islands	Bulgaria	Palau
South Sudan	United States Virgin Islands	Croatia	Papua New Guinea
Sudan	United States of America	Czechia	Pitcairn Islands
Togo	Uruguay	Denmark	Samoa
Tunisia	Venezuela	Estonia	Solomon Islands
Uganda	Afghanistan	Faroe Islands	Tokelau
United Republic of Tanzania	Armenia	Finland	Tonga
Zambia	Azerbaijan	France	Tuvalu
Zimbabwe	Bahrain	Germany	Vanuatu
Anguilla	Bangladesh	Gibraltar	Wallis and Futuna

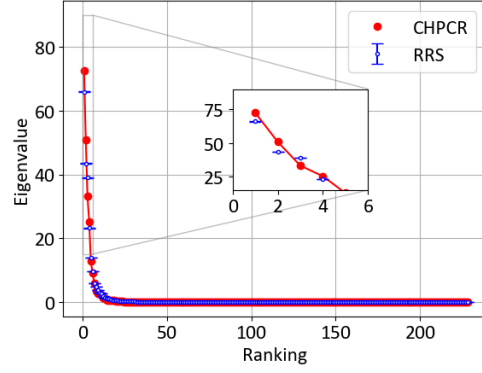
SI Figure 3: Correspondence of colours with countries. These colours are used in SI Figures 1 and 2.



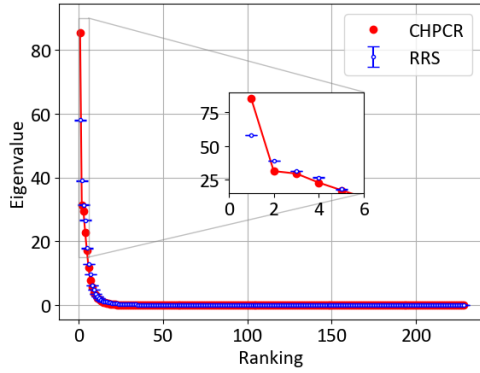
SI Figure 4: Pair plots between auxiliary data points.



(a) 2020

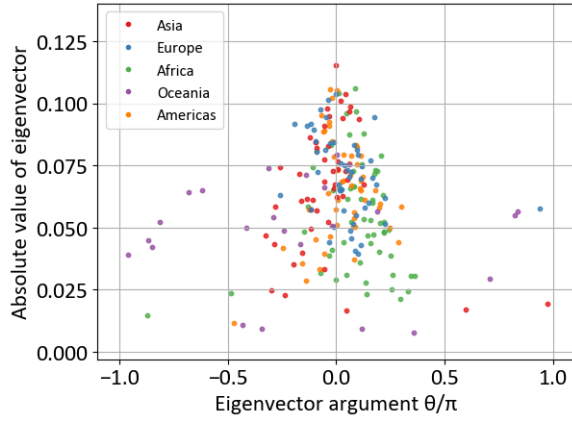


(b) 2021

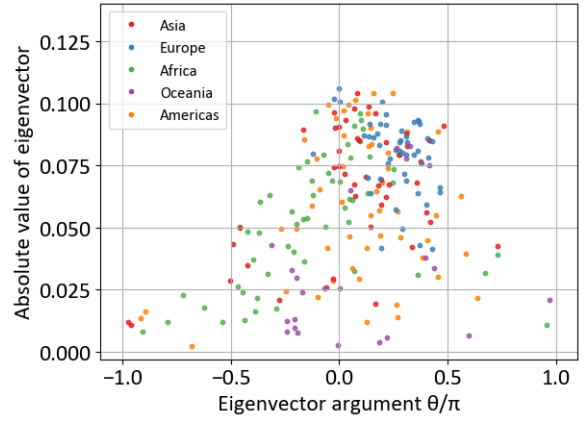


(c) 2022

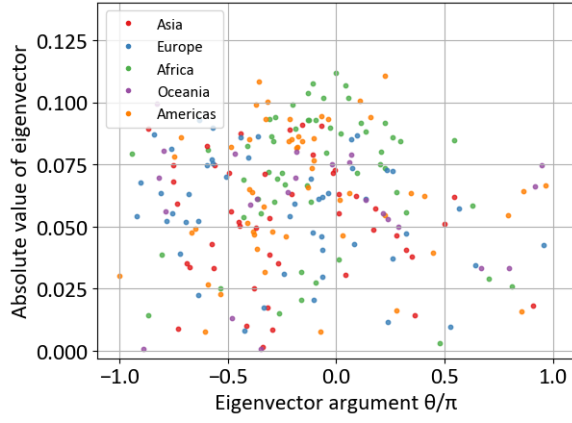
SI Figure 5: Scree plots of CHPCA and the RRS. Each panel covers different years, i.e., 2020, 2021, and 2020. The error bars for the RRS indicate the 1% significance level, which is 2.33 times the standard error.



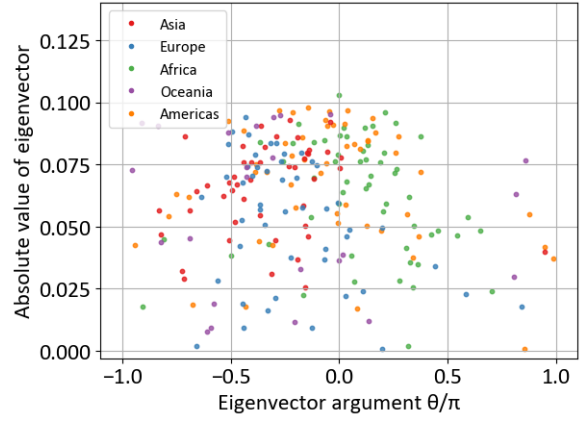
(a) Entire period



(b) 2020

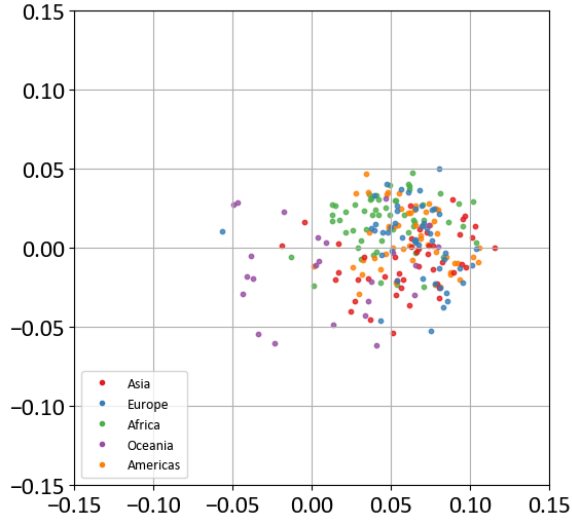


(c) 2021

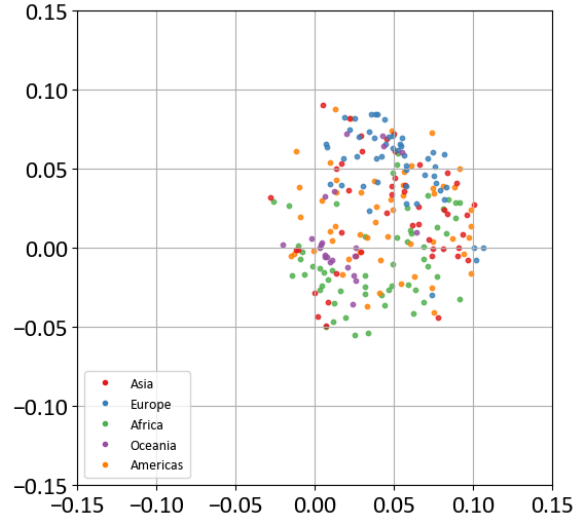


(d) 2022

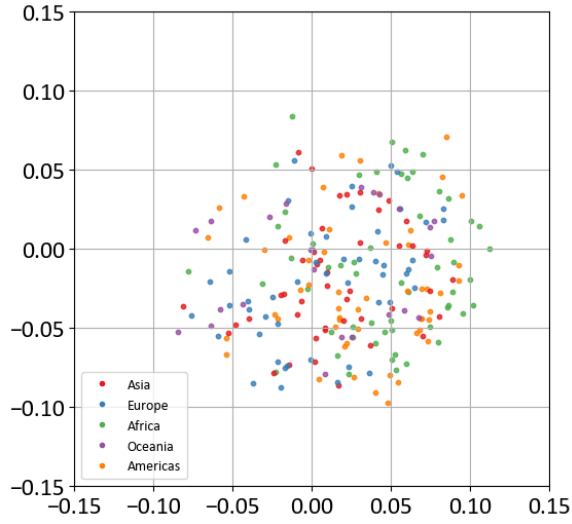
SI Figure 6: Eigenvectors with the first eigenvalue coloured by region. The abscissa corresponds to the argument, and the ordinate corresponds to the absolute value (amplitude) of the eigenvector. Note that time progresses from right to left. Panels (a-d) show the entire period, 2020, 2021, and 2022, respectively.



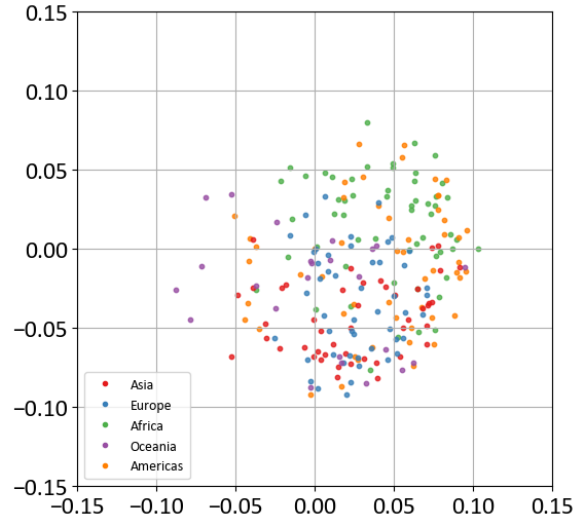
(a) Entire period



(b) 2020



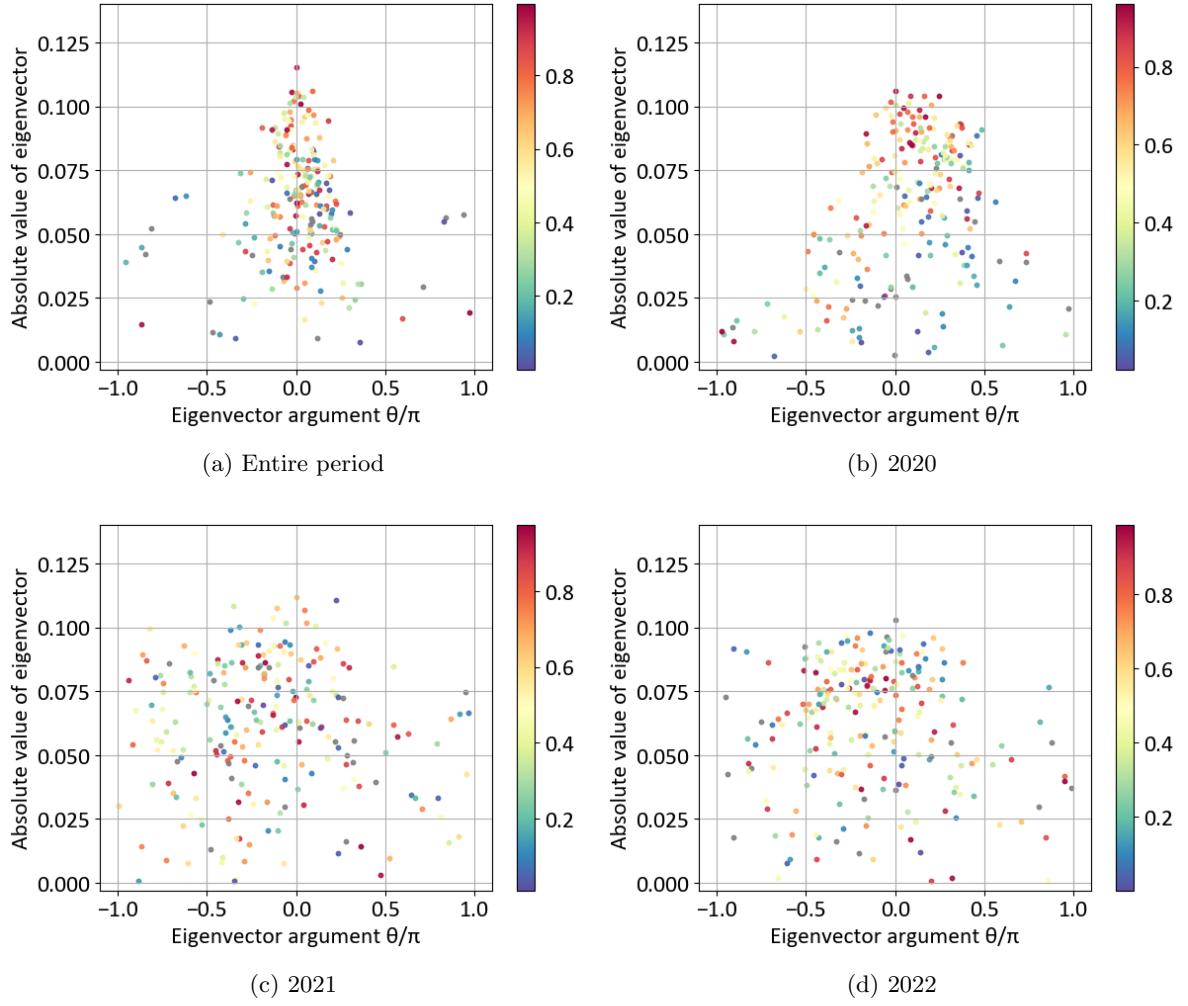
(c) 2021



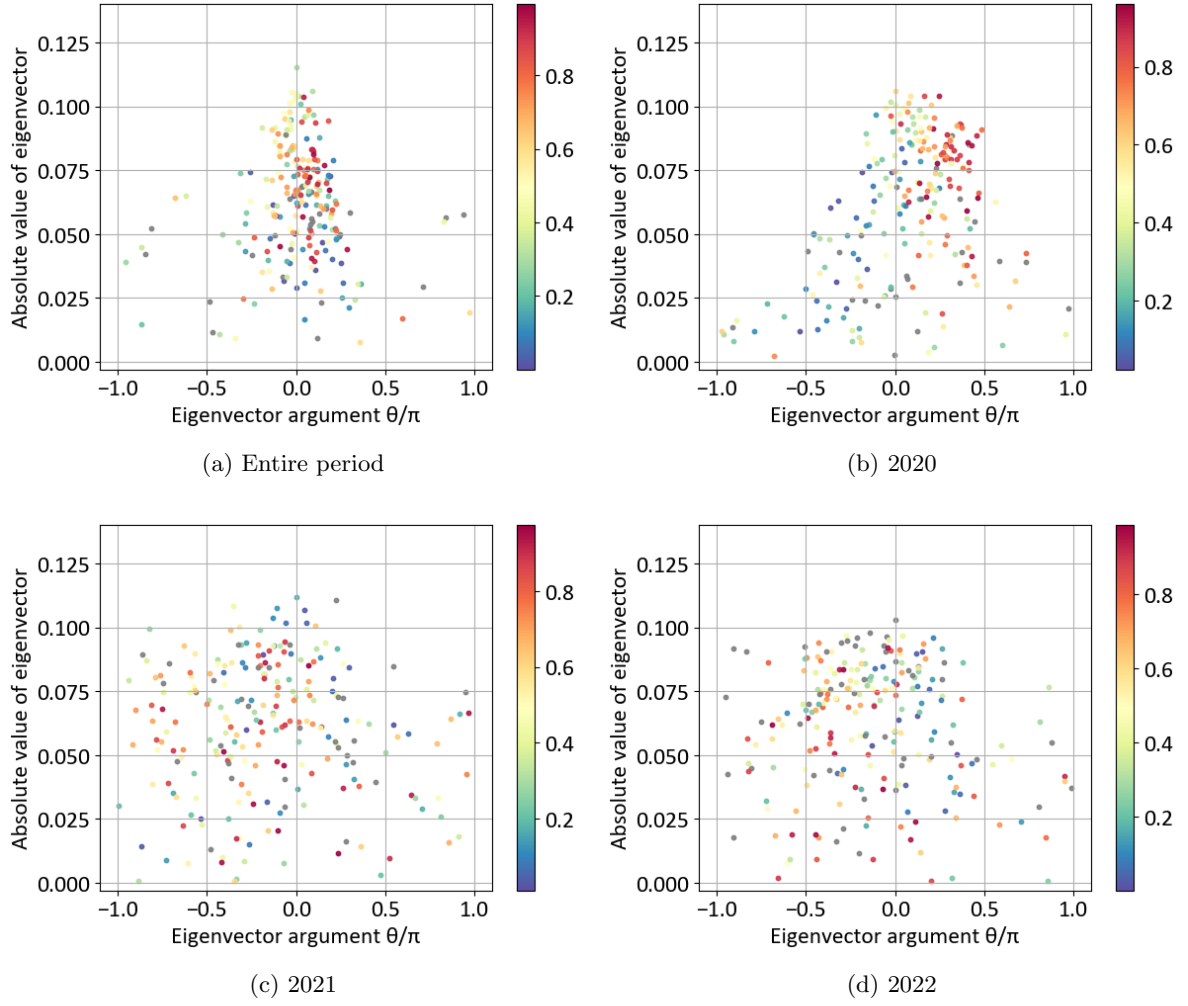
(d) 2022

SI Figure 7: Eigenvectors, with the first eigenvalue coloured by region. The abscissa corresponds to the real axis, and the ordinate corresponds to the imaginary axis. Panels (a-d) represent the entire period, 2020, 2021, and 2022, respectively. Note that time progresses from right to left.

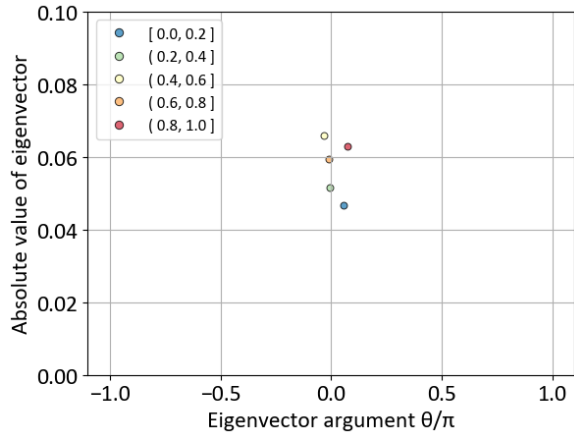




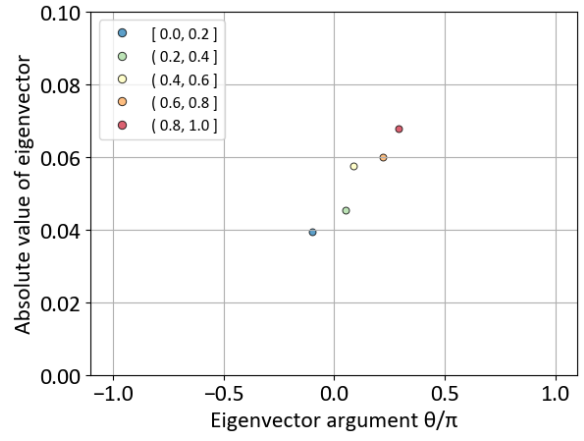
SI Figure 8: Eigenvectors with the first eigenvalue coloured according to population. The abscissa corresponds to the argument, and the ordinate corresponds to the absolute value (amplitude) of the eigenvector. Note that time progresses from right to left. Panels (a-d) represent the entire period, 2020, 2021, and 2022, respectively. The population data for each year are used for the analysis of the corresponding year, while the 2020 population data are used for the analysis of the entire period. In addition, the colour denotes the rank of the analysed countries by population. If a country has no population record, it is coloured grey.



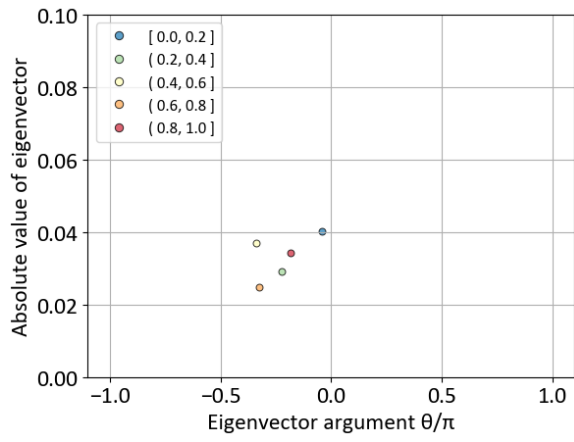
SI Figure 9: Eigenvectors, with the first eigenvalue coloured according to the GDP per capita. The abscissa corresponds to the real axis, and the ordinate corresponds to the imaginary axis. Panels (a-d) represent the entire period, 2020, 2021, and 2022, respectively. The population and GDP data for each year are used for the corresponding year, while the 2020 population and GDP data are used for the analysis of the entire period. In addition, the colour indicates the rank of the analysed countries by GDP per capita. If a country has no population or GDP record, it is coloured grey.



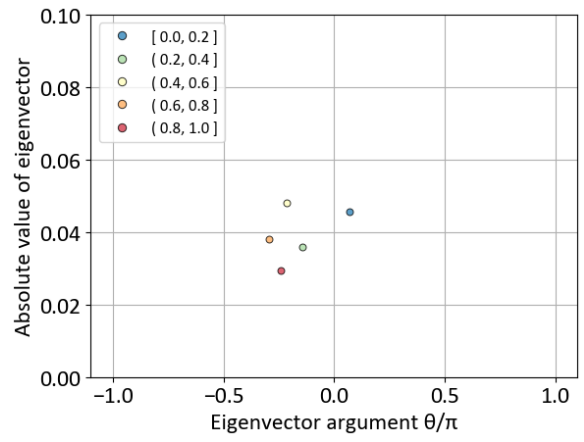
(a) Entire period



(b) 2020

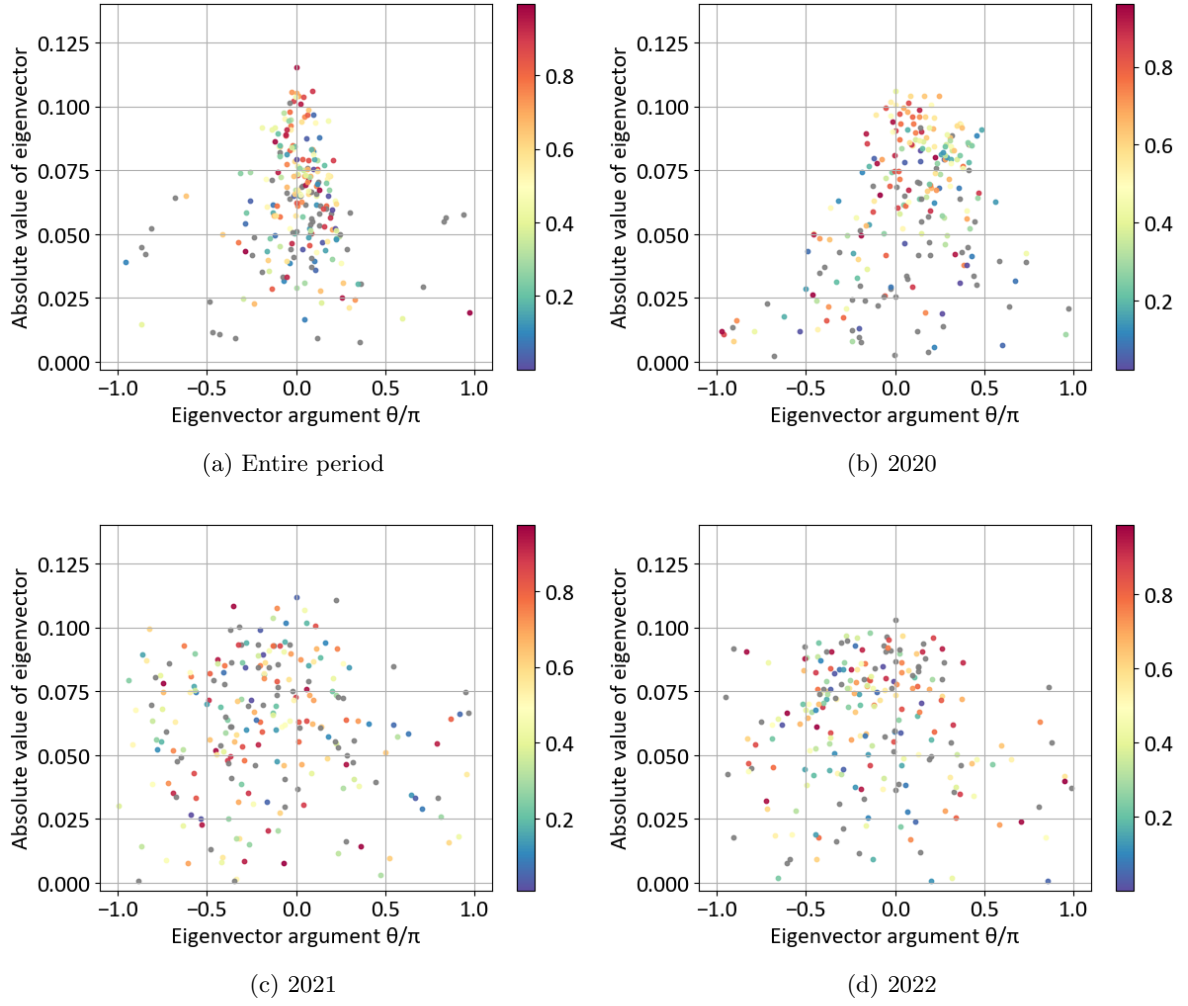


(c) 2021

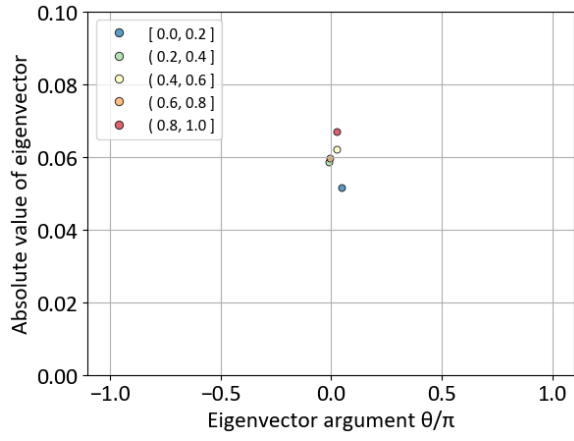


(d) 2022

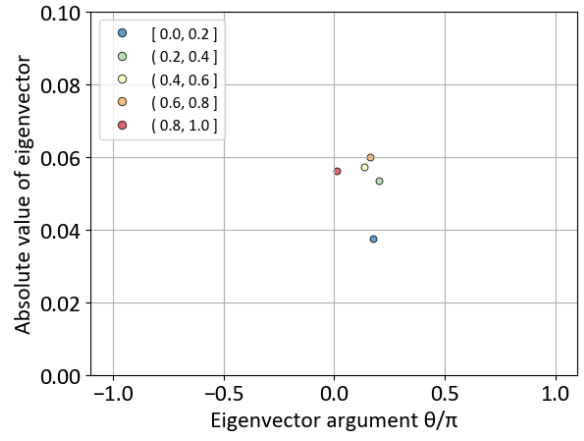
SI Figure 10: Barycentres for five groups of GDP per capita based on rank. The abscissa corresponds to the argument, and the ordinate corresponds to the absolute value (amplitude) of the eigenvector. Panels (a-d) represent the entire period, 2020, 2021, and 2022, respectively. Note that time progresses from right to left.



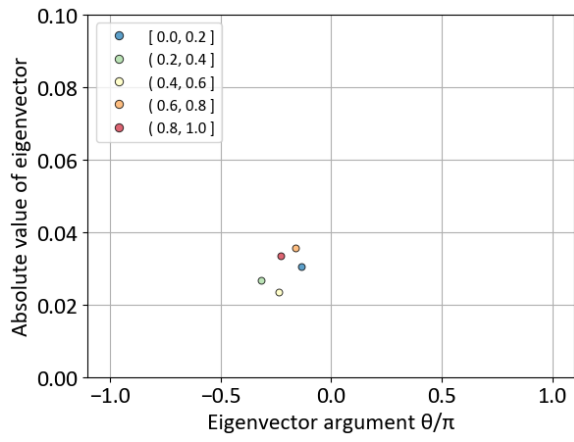
SI Figure 11: Eigenvectors, with the first eigenvalue coloured according to the stringency index. The abscissa corresponds to the argument, and the ordinate corresponds to the absolute value (amplitude) of the eigenvector. Note that time progresses from right to left. Panels (a-d) represent the entire period, 2020, 2021, and 2022, respectively. The mean of each year's stringency index data is used for the corresponding year, while the mean of the entire period is used for the analysis of the entire period. In addition, the colour indicates the rank of the countries by stringency index. If a country has no stringency index record, it is coloured grey.



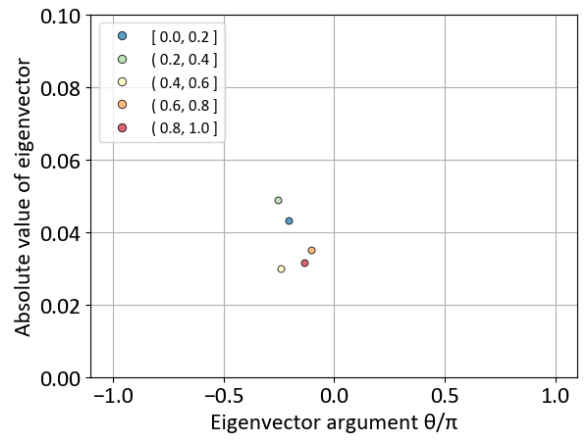
(a) Entire period



(b) 2020

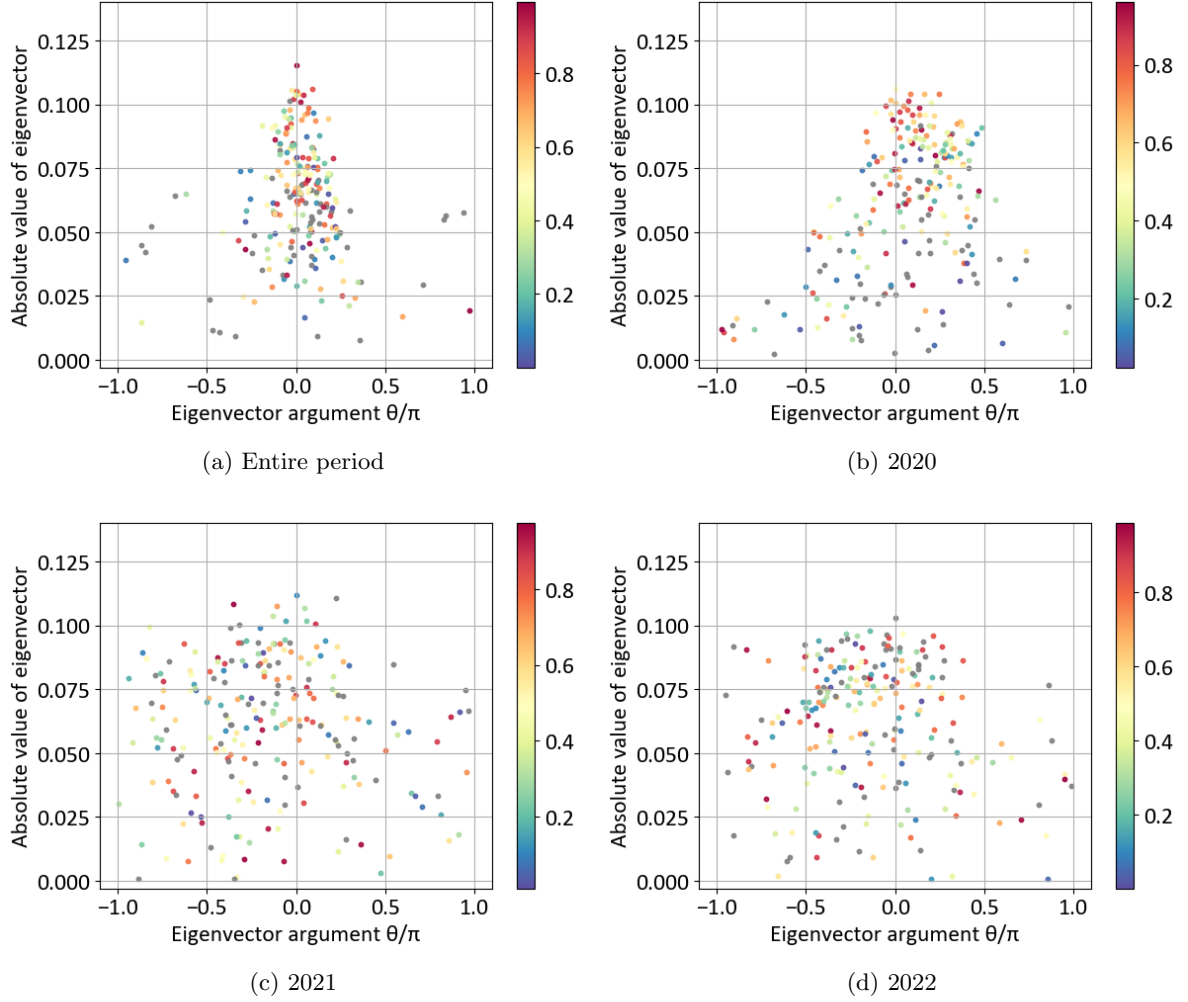


(c) 2021

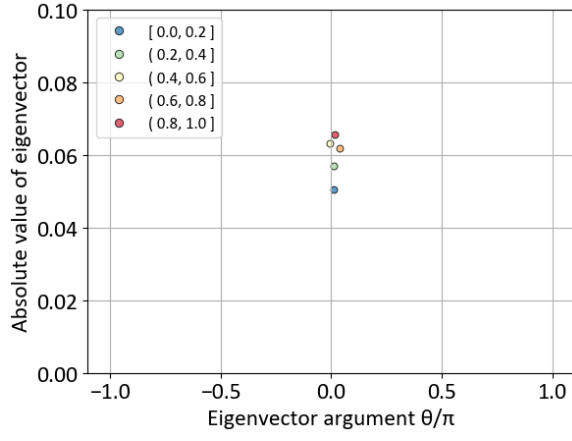


(d) 2022

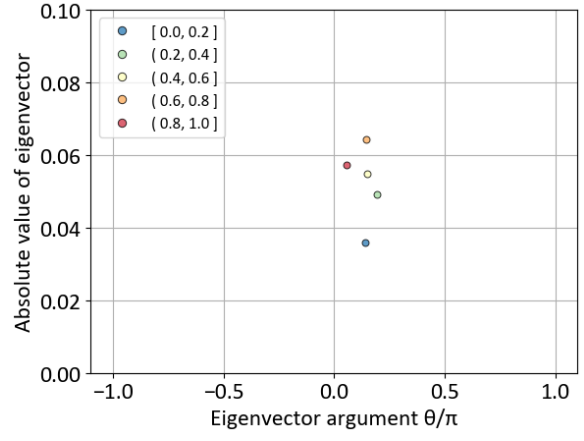
SI Figure 12: Barycentres for five groups of each stringency index based on rank. The abscissa corresponds to the argument, and the ordinate corresponds to the absolute value (amplitude) of the eigenvector. Panels (a-d) represent the entire period, 2020, 2021, and 2022, respectively. Note that time progresses from right to left.



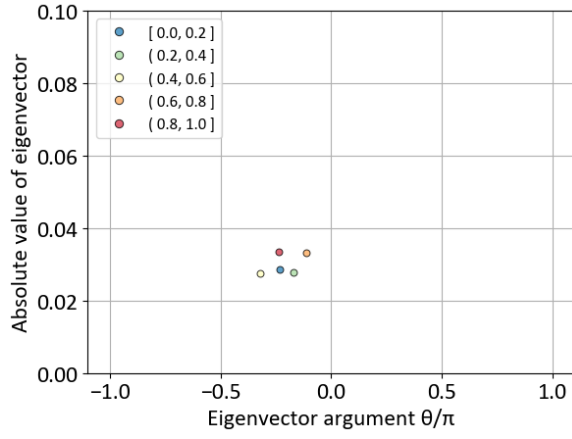
SI Figure 13: Eigenvectors, with the first eigenvalue coloured according to the containment and health index. The abscissa corresponds to the argument, and the ordinate corresponds to the absolute value (amplitude) of the eigenvector. Note that time progresses from right to left. Panels (a-d) represent the entire period, 2020, 2021, and 2022, respectively. The mean of each year's stringency index data is used for the corresponding year, while the mean of the entire period is used for the entire period analyses. In addition, the colour indicates the rank by the containment and health index among the analysed countries. If a country has no containment and health index record, it is coloured grey.



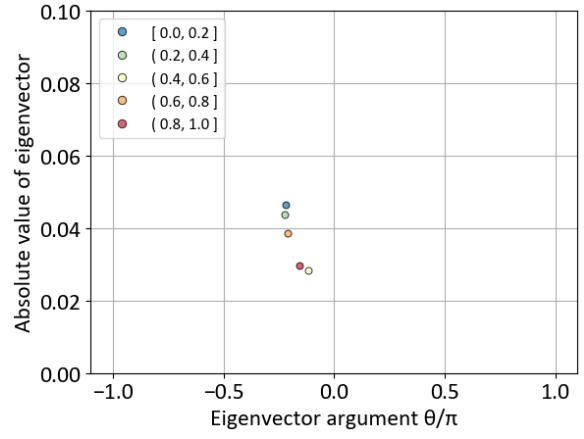
(a) Entire period



(b) 2020

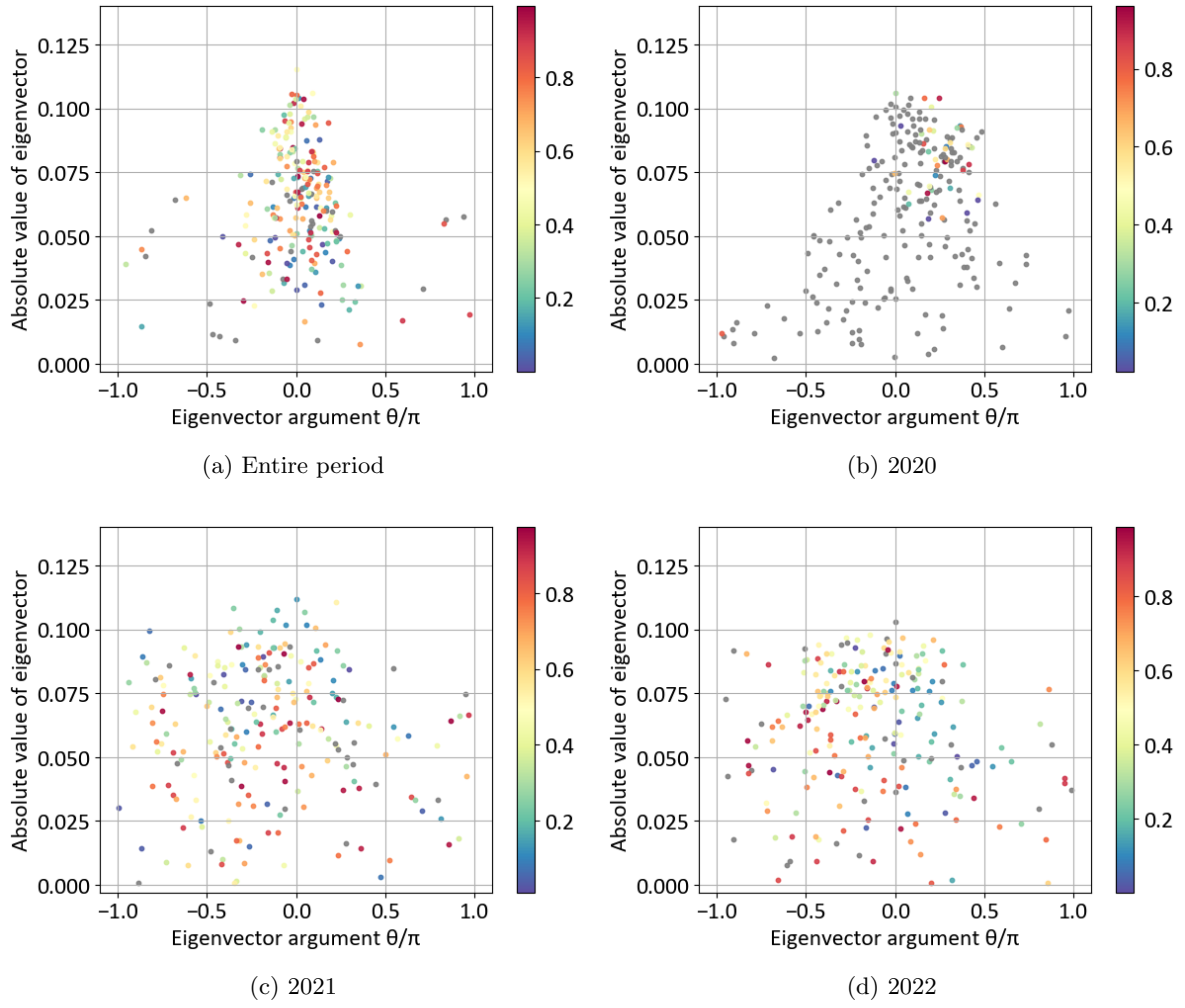


(c) 2021



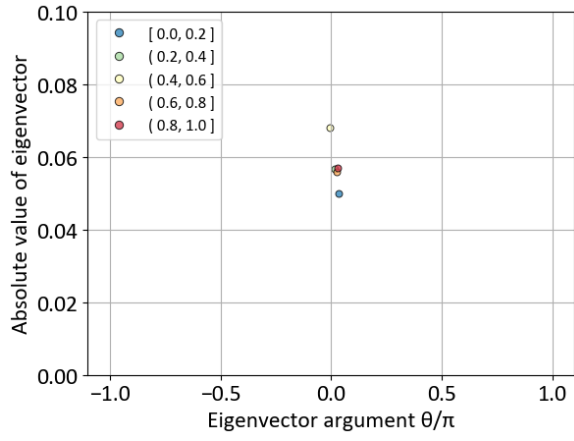
(d) 2022

SI Figure 14: Barycentres for five groups of the containment and health index group based on rank. The abscissa corresponds to the argument, and the ordinate corresponds to the absolute value (amplitude) of the eigenvector. Panels (a-d) represent the entire period, 2020, 2021, and 2022, respectively. Note that time progresses from right to left.

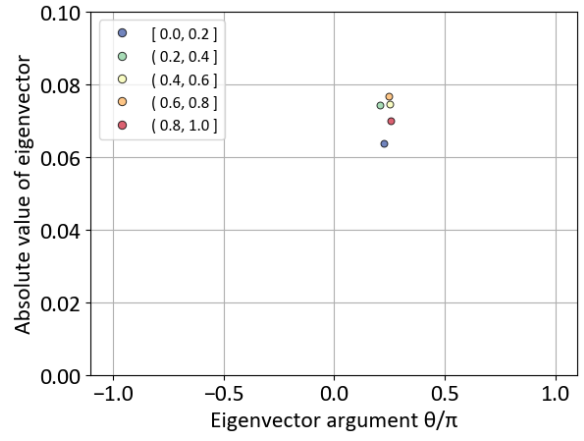


SI Figure 15: Eigenvectors, with the first eigenvalue coloured according to the vaccination rate. The abscissa corresponds to the argument, and the ordinate corresponds to the absolute value (amplitude) of the eigenvector. Note that time progresses from right to left. Panels (a-d) represent the entire period, 2020, 2021, and 2022, respectively. Each year's vaccination rate is used for the corresponding year, while the average vaccination rate is used for the entire period. In addition, the colour indicates the rank of the countries by vaccination rate. If a country has no vaccination record in the entire period or in 2020, it is coloured grey.

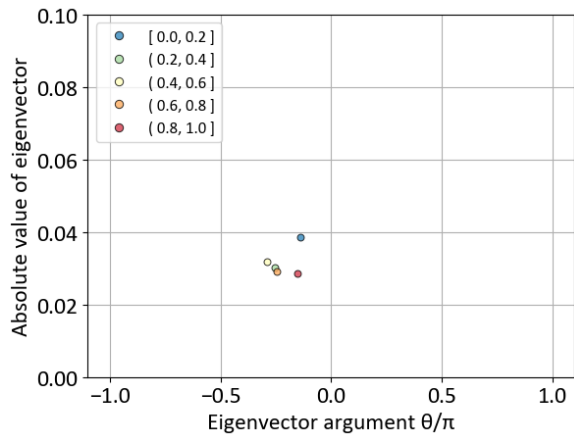




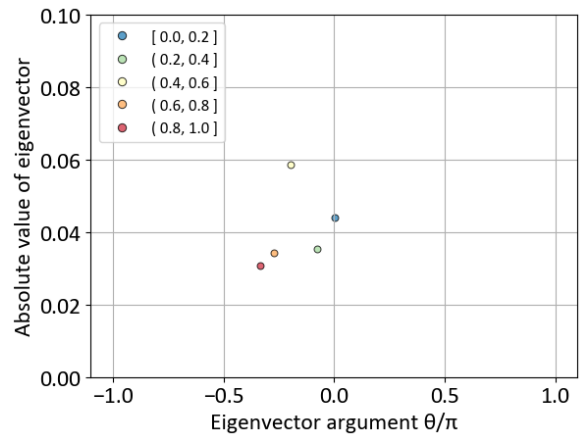
(a) Entire period



(b) 2020

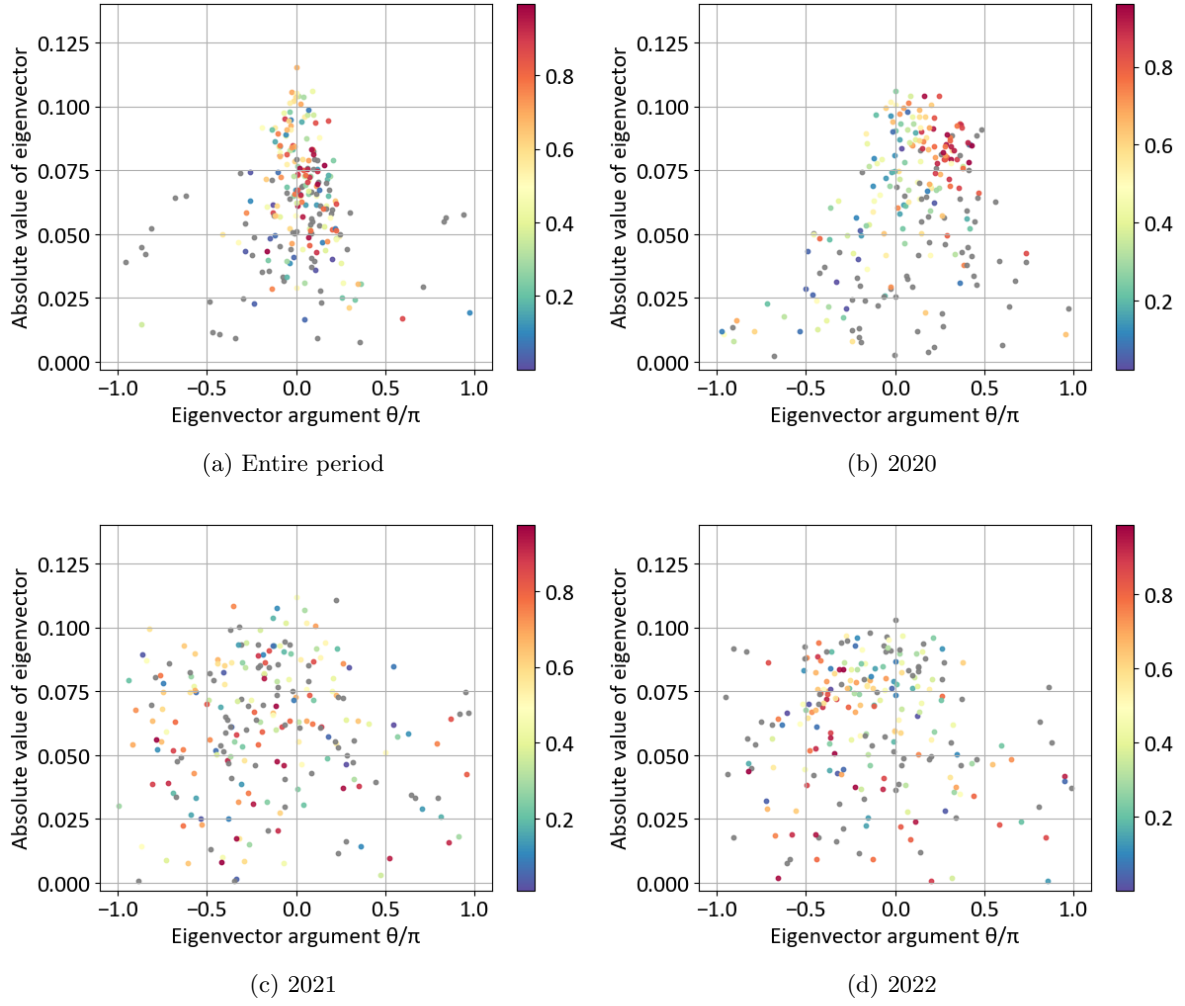


(c) 2021

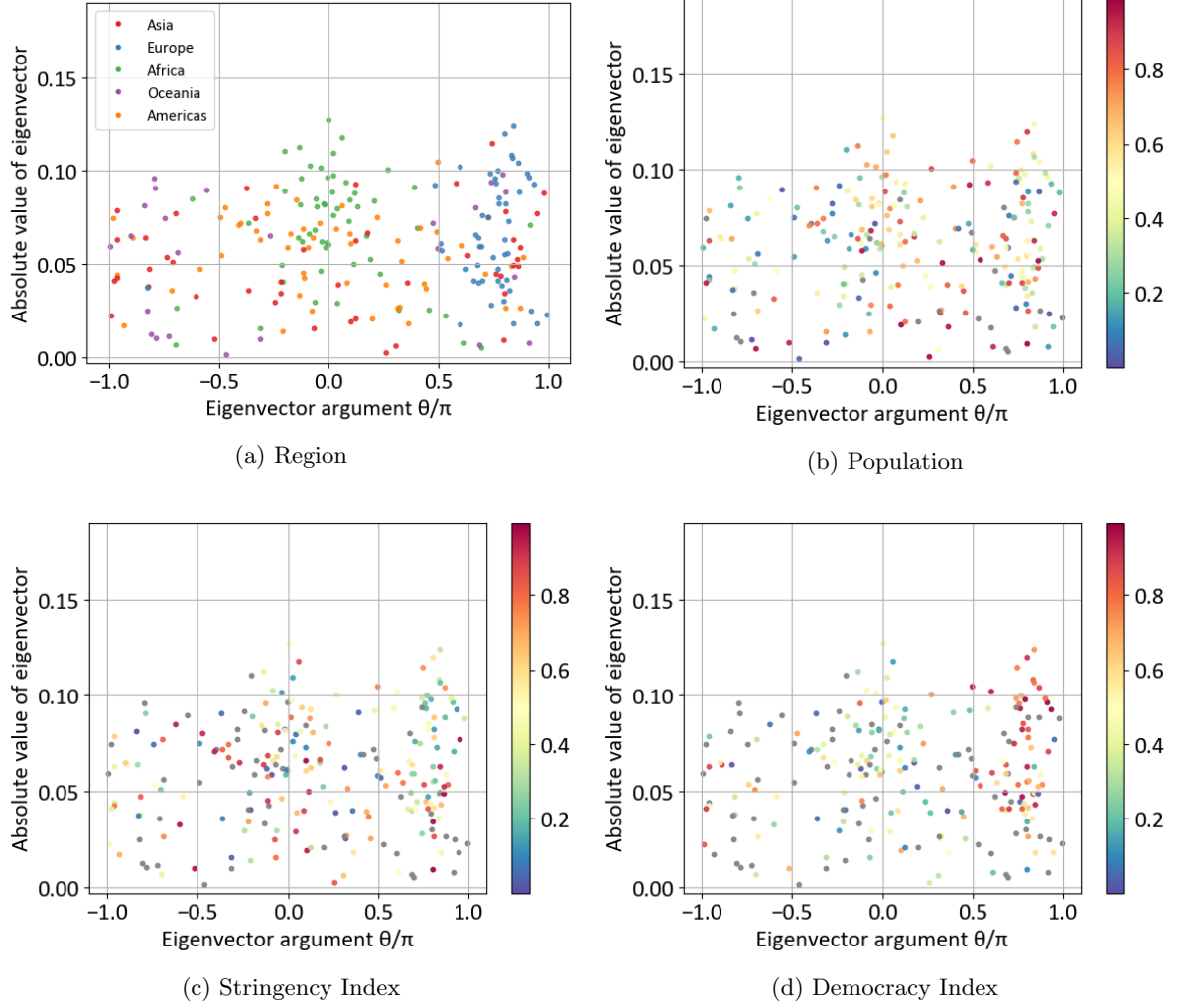


(d) 2022

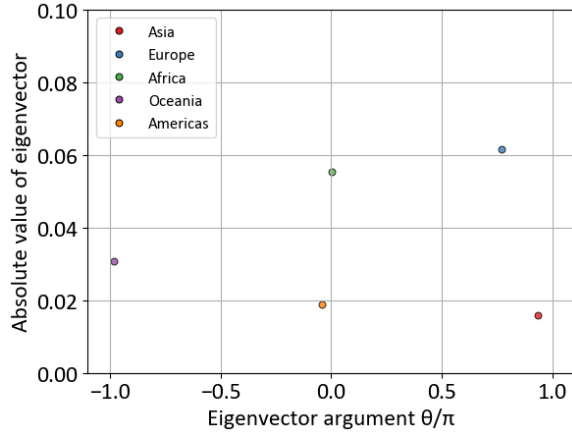
SI Figure 16: Barycentres for five groups of the vaccination rate based on rank. The abscissa corresponds to the real axis, and the ordinate corresponds to the imaginary axis. Panels (a-d) represent the entire period, 2020, 2021, and 2022, respectively. Note that time progresses from right to left.



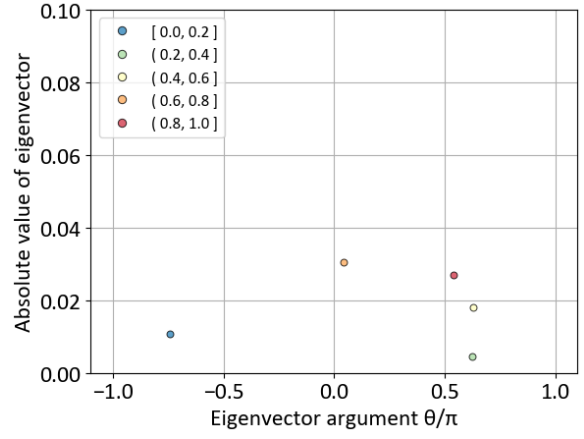
SI Figure 17: Eigenvectors, with the first eigenvalue coloured according to the democracy index. The democracy index was obtained from the Economist Intelligence Unit [1]. The abscissa corresponds to the argument, and the ordinate corresponds to the absolute value (amplitude) of the eigenvector. Note that time progresses from right to left. Panels (a-d) represent the entire period, 2020, 2021, and 2022, respectively. Each year's democracy index data are used for the analysis of the corresponding year, while the 2020 democracy index data are used for the analysis of the entire period. In addition, the colour represents the rank of the analysed countries by the democracy index. If a country has no democracy index record, it is coloured grey.



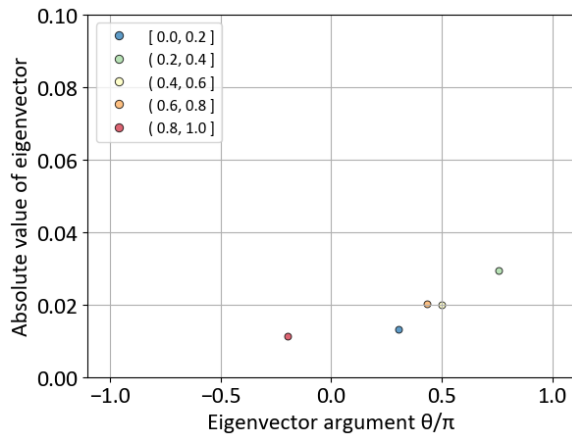
SI Figure 18: The second eigenvectors for the entire period of data. The panels are coloured by (a) region, (b) population, (c) stringency index [2], and (d) democracy index [1]. If a country has no population, stringency index, or democracy index data, it is coloured grey. The abscissa corresponds to the argument, and the ordinate corresponds to the absolute value (amplitude) of the eigenvector. Note that time progresses from right to left.



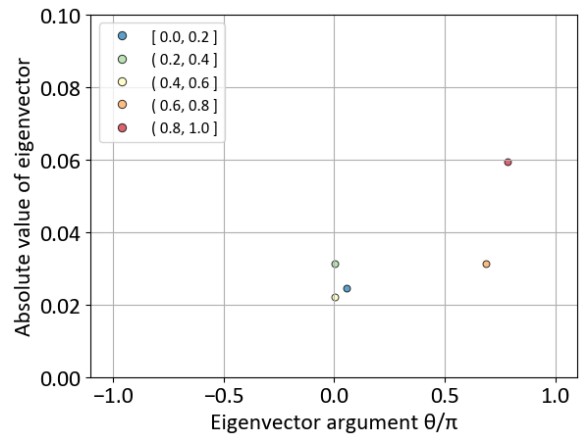
(a) Region



(b) Population

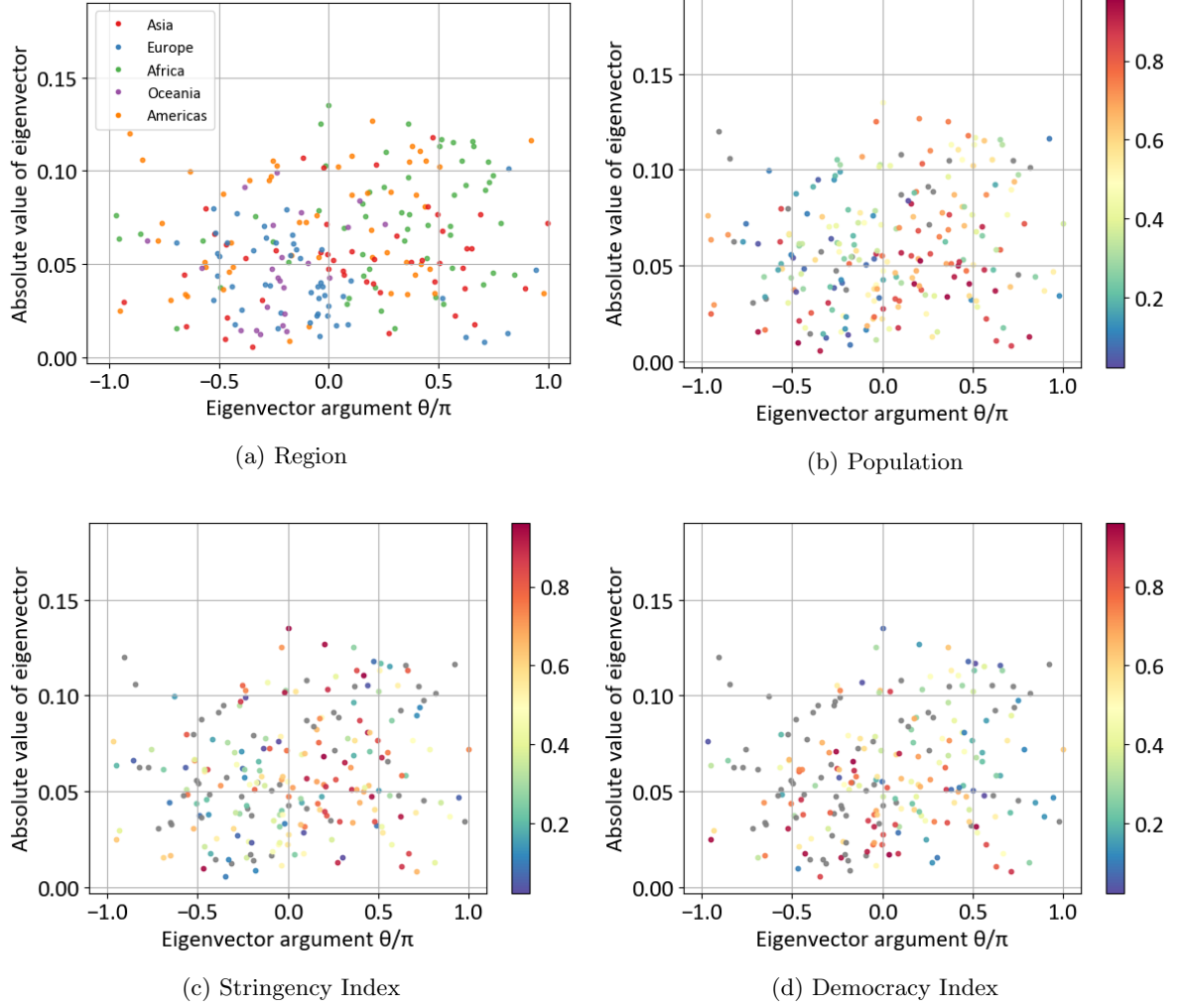


(c) Stringency Index

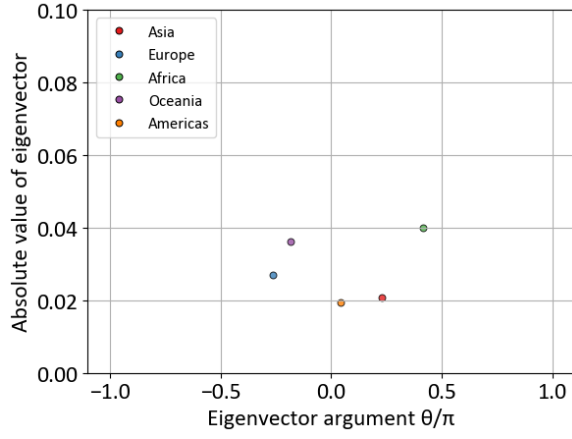


(d) Democracy Index

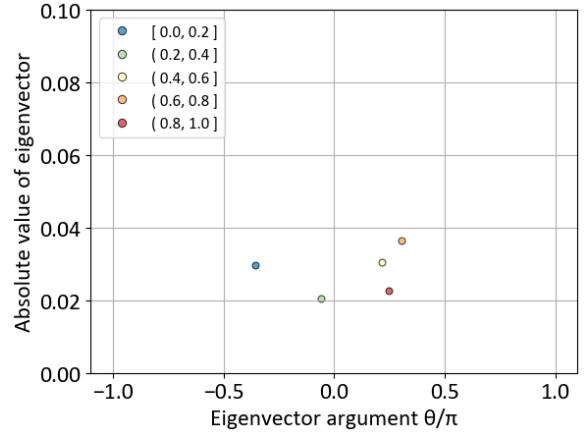
SI Figure 19: Barycentres of the second eigenvectors for data of the entire period. The panels are coloured by (a) region, (b) population, (c) stringency index [2], and (d) democracy index [1]. The abscissa corresponds to the argument, and the ordinate corresponds to the absolute value (amplitude) of the eigenvector. Note that time progresses from right to left.



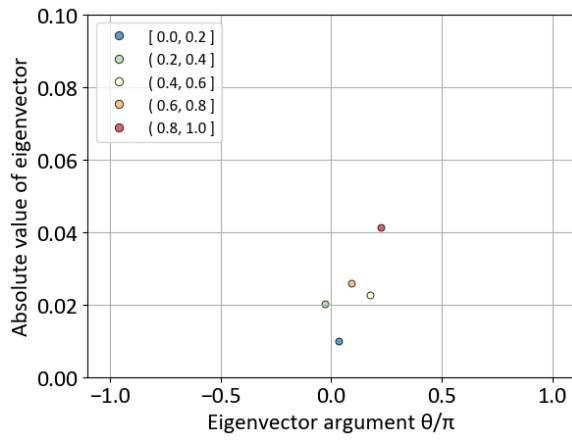
SI Figure 20: The second eigenvector for the 2020 data. The panels are coloured by (a) region, (b) population, (c) stringency index [2], and (d) democracy index [1]. If a country has no population, stringency index, or democracy index data, it is coloured grey. The abscissa corresponds to the real axis, and the ordinate corresponds to the imaginary axis. Note that time progresses from right to left.



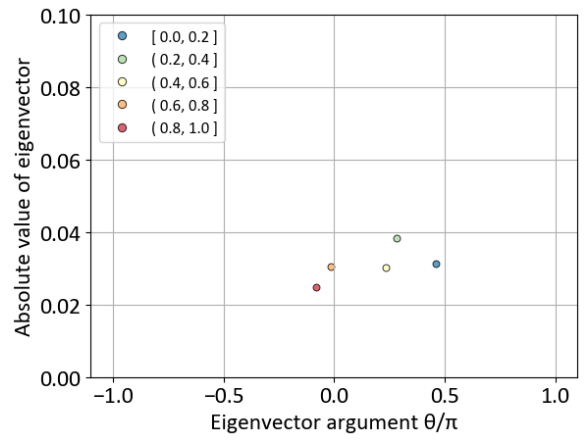
(a) Region



(b) Population

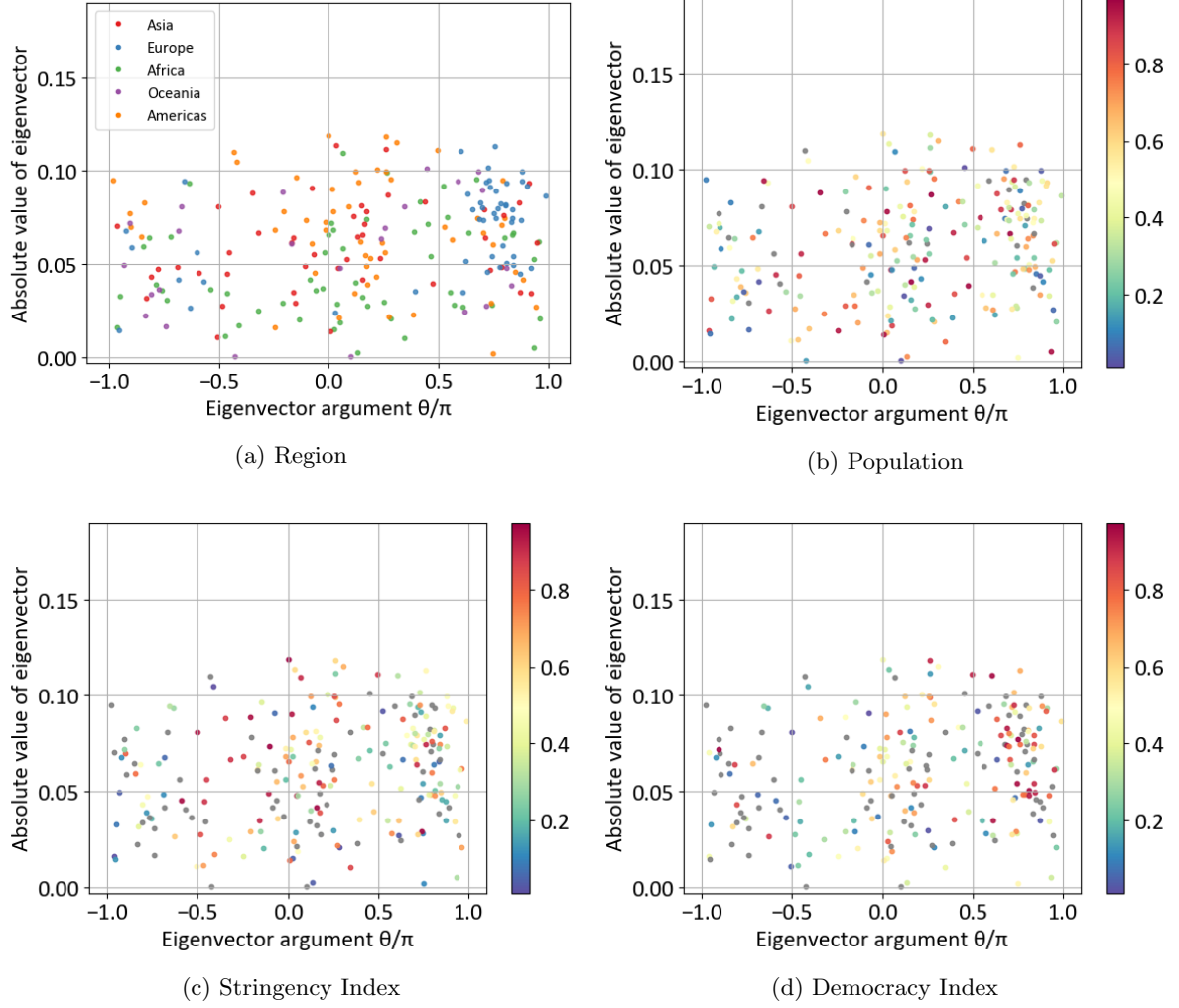


(c) Stringency Index

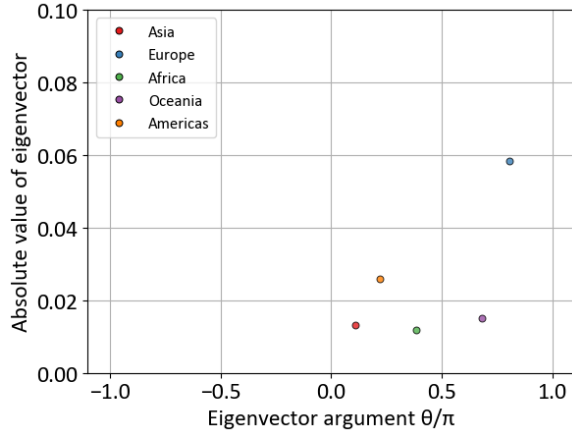


(d) Democracy Index

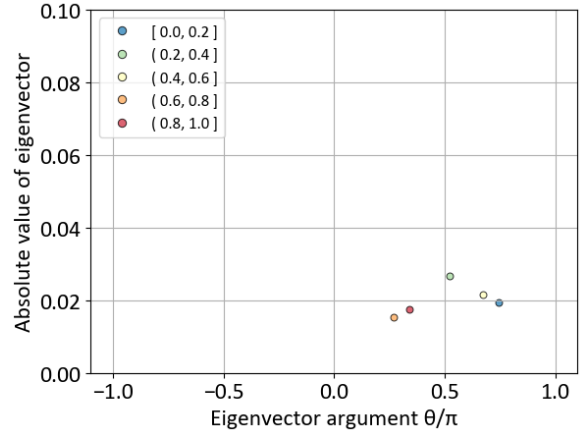
SI Figure 21: Barycentres of the second eigenvectors for the 2020 data. The panels are coloured by (a) region, (b) population, (c) stringency index [2], and (d) democracy index [1]. The abscissa corresponds to the argument, and the ordinate corresponds to the absolute value (amplitude) of the eigenvector. Note that time progresses from right to left.



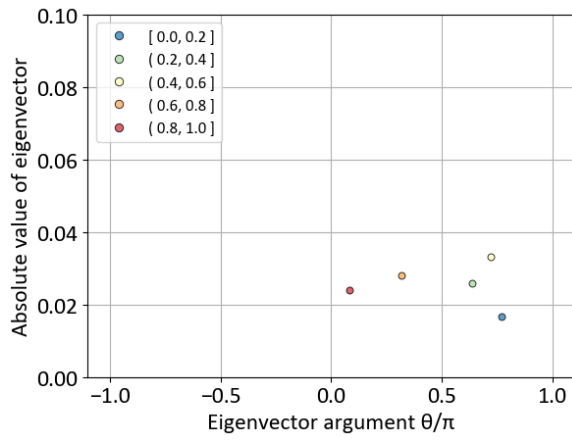
SI Figure 22: The second eigenvectors for the 2021 data. The panels are coloured by region, population, stringency index [2], and democracy index [1]. If a country has no population, stringency index, or democracy index data, it is coloured grey. The abscissa corresponds to the real axis, and the ordinate corresponds to the imaginary axis. Note that time progresses from right to left.



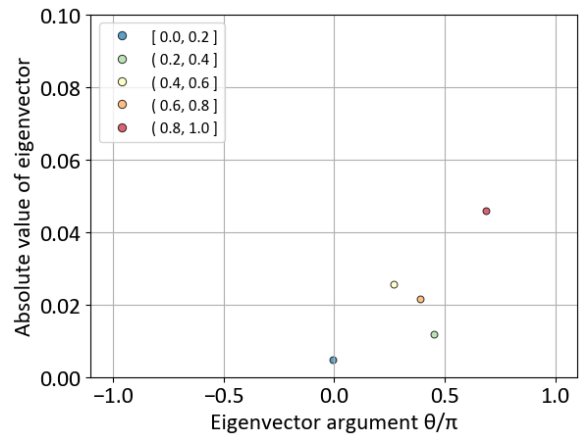
(a) Region



(b) Population



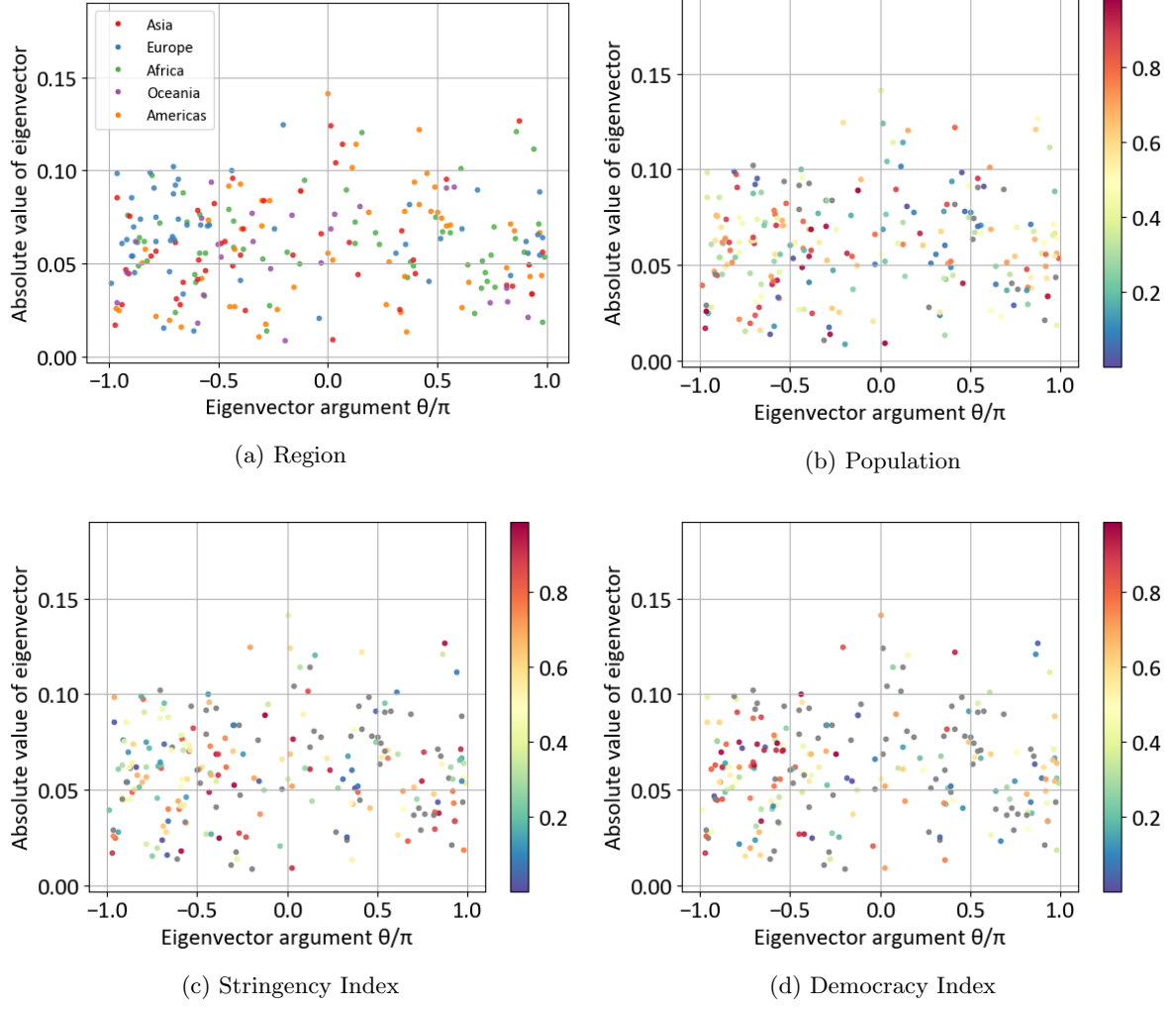
(c) Stringency Index



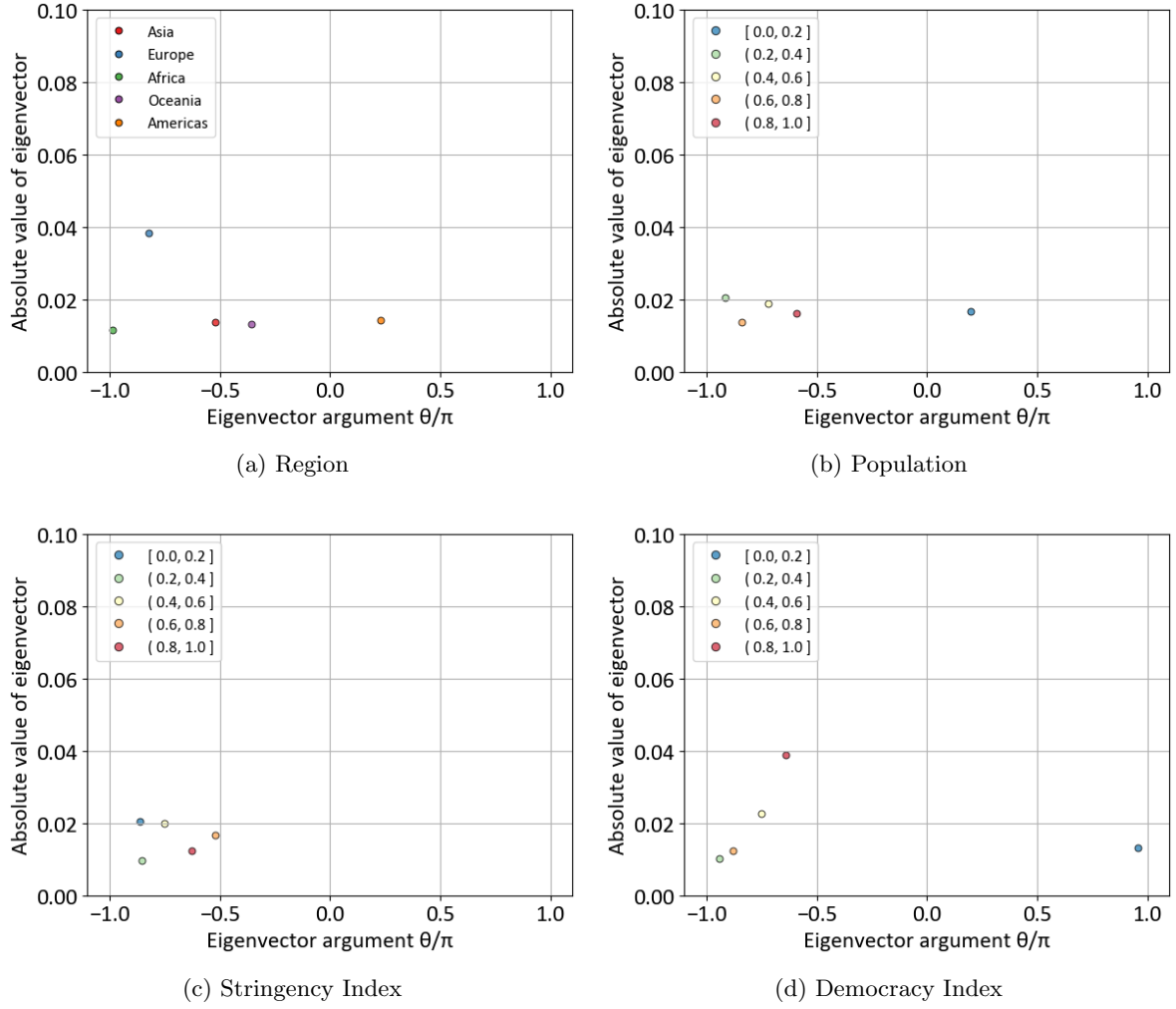
(d) Democracy Index

SI Figure 23: Barycentres of the second eigenvectors for the 2021 data. The panels are coloured by (a) region, (b) population, (c) stringency index [2], and (d) democracy index [1]. The abscissa corresponds to the argument, and the ordinate corresponds to the absolute value (amplitude) of the eigenvector. Note that time progresses from right to left.

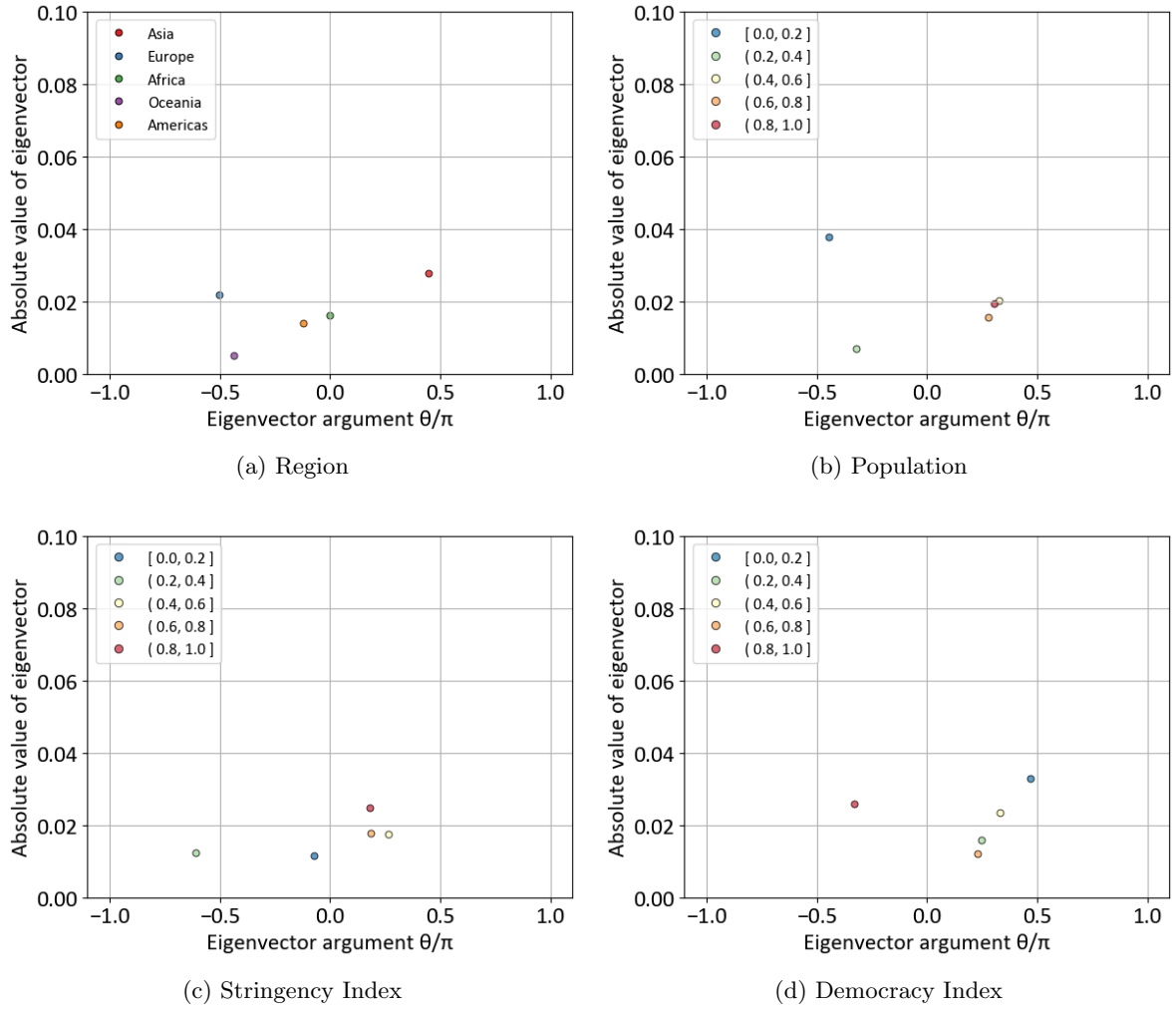




SI Figure 24: The second eigenvectors for the 2022 data. The panels are coloured by region, population, stringency index [2], and democracy index [1]. If a country has no population, stringency index, or democracy index data, it is coloured grey. The abscissa corresponds to the real axis, and the ordinate corresponds to the imaginary axis. Note that time progresses from right to left.



SI Figure 25: Barycentres of the second eigenvectors for the 2022 data. The panels are coloured by (a) region, (b) population, (c) stringency index [2], and (d) democracy index [1]. The abscissa corresponds to the argument, and the ordinate corresponds to the absolute value (amplitude) of the eigenvector. Note that time progresses from right to left.



SI Figure 26: Barycentres of the third eigenvectors for the data of the entire period. The panels are coloured by (a) region, (b) population, (c) stringency index [2], and (d) democracy index [1]. The abscissa corresponds to the argument, and the ordinate corresponds to the absolute value (amplitude) of the eigenvector. Note that time progresses from right to left.

## 2 Supplementary tables

The following list contains the tables referred to in the main text.

SI Table 1: Sample size of the auxiliary data.

SI Table 2: Mean distance from the barycentre. The mean distance is calculated for each group.

SI Table 1: Sample sizes of auxiliary data. The numbers indicates the number of observed countries in each dataset.

	2020	2021	2022
Population	265	265	265
GDP	257	251	233
Stringency Index	183	180	180
Containment Index	184	180	180
Vaccinations Rate	39	217	213
Democracy Index	167	167	167

SI Table 2: Mean distance from the barycentre. The mean distance is calculated for each group. The columns indicate the position within the five groups, which are divided by rank.

	Group	Entire Period	2020	2021	2022
Regions	Asia	0.030	0.044	0.046	0.041
	Europe	0.027	0.030	0.053	0.038
	Africa	0.027	0.040	0.055	0.044
	Oceania	0.046	0.031	0.057	0.053
	Americas	0.026	0.041	0.053	0.055
Population	First	0.036	0.034	0.054	0.058
	Second	0.032	0.042	0.053	0.049
	Third	0.029	0.043	0.054	0.047
	Fourth	0.028	0.044	0.055	0.047
	Fifth	0.032	0.044	0.053	0.050
GDP/Population	First	0.025	0.035	0.056	0.040
	Second	0.041	0.043	0.054	0.058
	Third	0.032	0.042	0.048	0.046
	Fourth	0.027	0.037	0.058	0.048
	Fifth	0.022	0.030	0.046	0.043
Stringency Index	First	0.028	0.046	0.063	0.038
	Second	0.032	0.038	0.050	0.046
	Third	0.032	0.048	0.053	0.048
	Fourth	0.031	0.044	0.054	0.055
	Fifth	0.030	0.039	0.047	0.059
Containment & Health Index	First	0.033	0.044	0.062	0.044
	Second	0.030	0.045	0.057	0.044
	Third	0.031	0.044	0.043	0.051
	Fourth	0.031	0.044	0.055	0.047
	Fifth	0.030	0.041	0.050	0.061
Vaccination Rate	First	0.028	0.038	0.062	0.045
	Second	0.034	0.032	0.056	0.050
	Third	0.029	0.028	0.056	0.051
	Fourth	0.031	0.022	0.050	0.054
	Fifth	0.032	0.035	0.045	0.047
Democracy Index	First	0.032	0.041	0.059	0.050
	Second	0.029	0.040	0.049	0.047
	Third	0.035	0.041	0.059	0.048
	Fourth	0.026	0.038	0.055	0.049
	Fifth	0.023	0.025	0.045	0.040

### 3 Analyses of the second eigenvectors

The second eigenvector for the 2020 data shows wide ranges for lead and lag, in contrast to the first eigenvector for the 2020 data (SI Figure 21). In terms of regions, the results are entirely different from those of the first eigenvector, with Africa leading and Europe lagging. This suggests that even during this period, Africa and Europe already show leading and lagging trends, respectively, as observed from 2021 to 2022. In terms of population, a lead-lag relationship can be observed, with countries with larger populations leading; however, population does not significantly affect the amplitude. The same results are found for the stringency index. Regarding the democracy index, the lead-lag relationships and amplitudes are completely opposite those observed with the first eigenvector. The leading trend is associated with a lower democracy index, and the lagging trend is associated with a higher democracy index. Moreover, a larger amplitude is associated with a lower democracy index, and a smaller amplitude is associated with a higher democracy index.

The second eigenvector for the 2021 data shows that the spread in the argument is the same as that for the first eigenvector (SI Figure 22), but there are some differences in the results. The first eigenvector does not show outstanding features in region or democracy index, but the second eigenvector captures the leading trend of European countries and a high democracy index. There are no distinctive results for the population or stringency indices, similar to the results of the analyses for the first eigenvector.

### References

- [1] Economist Intelligence. Democracy Index 2022. <https://www.eiu.com/n/campaigns/democracy-index-2022/>. Accessed: 2023-09-01.
- [2] Our World in Data. Covid-19: Stringency index. <https://ourworldindata.org/covid-stringency-index>. Accessed: 2023-09-01.