Supporting Information
Interplay between mobility, multi-seeding and lockdowns shapes COVID-19 local impact

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Country	Incidence onset	Mortality onset
England	10^{-5}	—
France	7×10^{-5}	10^{-6}
Germany	10^{-5}	2×10^{-6}
Italy	2×10^{-5}	—
Spain	7×10^{-5}	10^{-6}

Table A: **Table of incidence and mortality thresholds used to determine cases and deaths onsets for each administrative area in each country.**

Province	Incidence onset	Incidence peak time
East Anglia	2020-03-26	2020-04-11
Bedfordshire and Hertfordshire	2020-03-23	2020-04-13
Essex	2020-03-24	2020-04-08
West Midlands	2020-03-16	2020-03-31
Shropshire and Staffordshire	2020-03-22	2020-04-22
Tees Valley and Durham	2020-03-24	2020-04-08
Northumberland and Tyne and Wear	2020-03-21	2020-04-08
Cornwall and Isles of Scilly	2020-03-26	2020-04-02
Dorset and Somerset	2020-04-04	2020-04-15
Devon	2020-04-03	2020-04-20
West Yorkshire	2020-03-23	2020-04-07
South Yorkshire	2020-03-17	2020-03-31
North Yorkshire	2020-03-25	2020-05-04
East Yorkshire and Northern Lincolnshire	2020-03-28	2020-04-25
Inner London - West	2020-03-12	2020-04-08
Outer London - West and North West	2020-03-13	2020-04-04
Outer London - South	2020-03-13	2020-04-01
Outer London - East and North East	2020-03-18	2020-04-09
Inner London - East	2020-03-13	2020-04-06
Derbyshire and Nottinghamshire	2020-03-22	2020-04-11
Kent	2020-03-22	2020-04-19
Hampshire and Isle of Wight	2020-03-21	2020-04-10
Lancashire	2020-03-23	2020-04-16
Lincolnshire	2020-03-30	2020-04-18
Cheshire	2020-03-23	2020-04-08
Merseyside	2020-03-20	2020-04-08
Cumbria	2020-03-20	2020-04-12
Greater Manchester	2020-03-18	2020-04-08

Table B: **Table of epidemic features for NUTS2 of England, when available.**

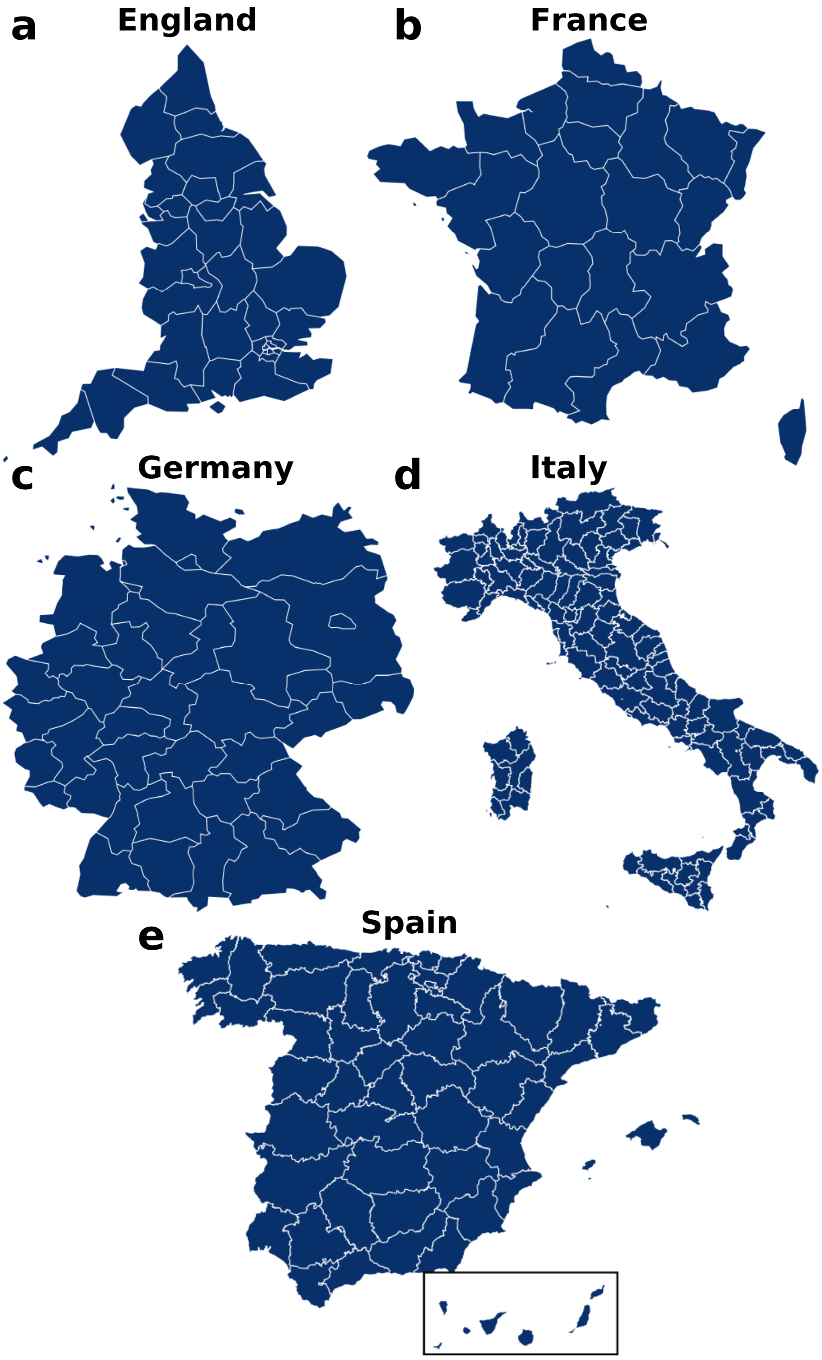

Fig A: **Local administrative subdivisions considered.** Covid and mobility data are aggregated at NUTS 2 level (regions or states) for England (**a**), France (**b**) and Germany (**c**), and at province (NUTS 3) level for Italy (**d**) and Spain (**e**). Administrative boundary data were obtained from GADM for Italy and Spain (`https://gadm.org`), and from EuroStat (`https://ec.europa.eu/eurostat`) for the rest of countries.

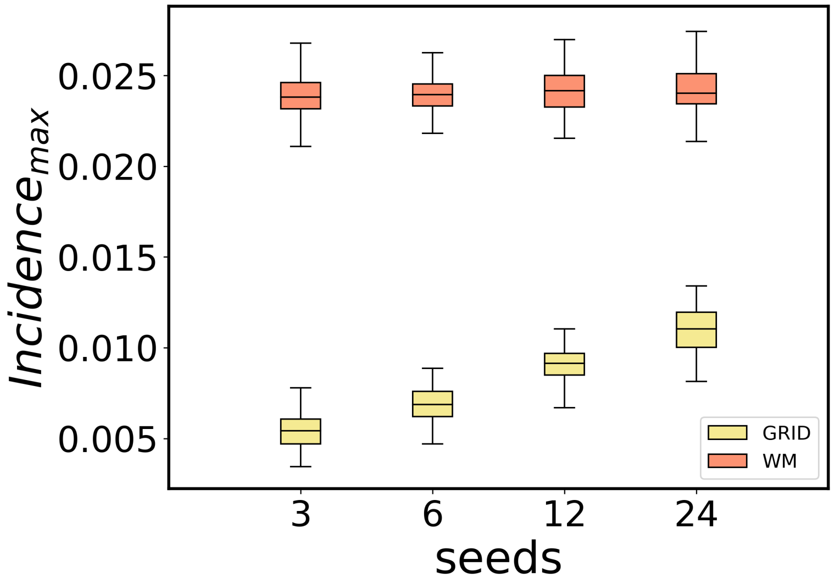

Fig B: **Incidence peaks boxplots for two populations simulation.** Distribution of incidence peaks as a function of imported seeds from the source for a gridded population in yellow and for a well-mixed population in orange.

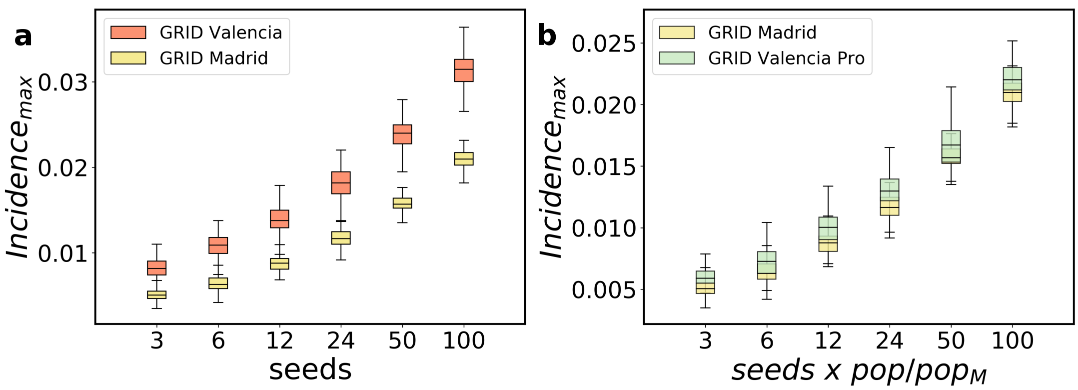

Fig C: **Incidence peaks dependence from seeds per capita.** Incidence peaks as a function of initial seeds in a single gridded population. **a** The same absolute number of initial seeds produces higher incidence peaks in a small population (Valencia) than in a bigger one (Madrid). **b** Setting the number of initial seeds in Valencia proportionally to the equivalent number of seeds per capita of Madrid, we get to similar incidence peaks.

Province	Incidence onset	Incidence peak time
Alsace	2020-03-11	2020-04-14
Auvergne	2020-03-23	2020-04-14
Rhône-Alpes	2020-03-16	2020-04-14
Pays de la Loire	2020-03-27	2020-04-08
Poitou-Charentes	2020-03-30	2020-04-14
Limousin	2020-03-28	2020-04-14
Aquitaine	2020-03-27	2020-04-21
Picardie	2020-03-15	2020-04-20
Nord-Pas de Calais	2020-03-26	2020-04-16
Bourgogne	2020-03-21	2020-04-23
Franche-Comté	2020-03-16	2020-04-15
Provence-Alpes-Côte d'Azur	2020-03-18	2020-04-16
Mayotte	2020-03-24	2020-04-03
Champagne-Ardenne	2020-03-22	2020-04-15
Lorraine	2020-03-15	2020-04-15
Ile-de-France	2020-03-20	2020-04-14
Midi-Pyrénées	2020-03-27	2020-04-14
Languedoc-Roussillon	2020-03-18	2020-04-07
Bretagne	2020-03-18	2020-03-29
Centre - Val de Loire	2020-03-21	2020-04-15
Corse	2020-03-10	2020-03-27
Basse-Normandie	2020-03-19	2020-04-12
Haute-Normandie	2020-03-21	2020-04-07
La Réunion	nan	2020-03-31
Guyane	2020-03-21	2020-03-29
Martinique	2020-03-27	2020-04-01
Guadeloupe	2020-03-19	2020-03-30

Table C: **Table of epidemic features for NUTS2 of France, when available.**

Province	Incidence onset	Incidence peak time
Karlsruhe	2020-03-12	2020-04-02
Freiburg	2020-03-11	2020-04-02
Stuttgart	2020-03-10	2020-03-26
Berlin	2020-03-11	2020-03-26
Tübingen	2020-03-11	2020-03-25
Hannover	2020-03-11	2020-03-25
Lüneburg	2020-03-15	2020-03-31
Braunschweig	2020-03-17	2020-03-27
Weser-Ems	2020-03-15	2020-03-26
Schleswig-Holstein	2020-03-16	2020-04-02
Dresden	2020-03-16	2020-03-26
Leipzig	2020-03-15	2020-04-02
Chemnitz	2020-03-16	2020-04-02
Hamburg	2020-03-10	2020-03-25
Brandenburg	2020-03-16	2020-04-08
Rheinhessen-Pfalz	2020-03-12	2020-04-02
Trier	2020-03-13	2020-03-28
Koblenz	2020-03-11	2020-03-26
Schwaben	2020-03-12	2020-04-02
Unterfranken	2020-03-12	2020-04-03
Mittelfranken	2020-03-17	2020-04-02
Oberfranken	2020-03-15	2020-04-03
Oberpfalz	2020-03-12	2020-04-02
Niederbayern	2020-03-12	2020-04-01
Oberbayern	2020-03-10	2020-03-26
Mecklenburg-Vorpommern	2020-03-17	2020-03-18
Thüringen	2020-03-17	2020-03-26
Sachsen-Anhalt	2020-03-17	2020-03-26
Darmstadt	2020-03-15	2020-03-26
Gießen	2020-03-15	2020-03-24
Kassel	2020-03-13	2020-04-02
Bremen	2020-03-10	2020-05-07
Köln	2020-03-05	2020-04-02
Münster	2020-03-12	2020-04-01
Düsseldorf	2020-03-12	2020-04-08
Saarland	2020-03-12	2020-04-01
Detmold	2020-03-11	2020-04-02
Arnsberg	2020-03-16	2020-04-02

Table D: **Table of epidemic features for NUTS2 of Germany, when available.**

Province	Incidence onset	Incidence peak time	Province	Incidence onset	Incidence peak time
Torino	2020-03-12	2020-04-16	Perugia	2020-03-14	2020-03-27
Vercelli	2020-03-11	2020-04-11	Terni	2020-03-09	2020-03-27
Novara	2020-03-12	2020-04-10	Viterbo	2020-03-17	2020-03-28
Cuneo	2020-03-14	2020-04-13	Rieti	2020-03-20	2020-03-31
Asti	2020-03-01	2020-04-21	Roma	2020-03-18	2020-03-22
Alessandria	2020-03-05	2020-04-05	Latina	2020-03-19	2020-03-21
Aosta	2020-03-06	2020-03-28	Frosinone	2020-03-21	2020-03-27
Imperia	2020-03-11	2020-04-06	Caserta	nan	2020-03-25
Savona	2020-02-27	2020-04-04	Benevento	2020-03-29	2020-03-31
Genova	2020-03-11	2020-04-07	Napoli	2020-03-20	2020-04-02
La Spezia	2020-03-08	2020-04-04	Avellino	2020-03-15	2020-04-02
Varese	2020-03-11	2020-03-28	Salerno	2020-03-27	2020-03-29
Como	2020-03-10	2020-04-12	'L''Aquila'	2020-03-24	2020-04-03
Sondrio	2020-03-11	2020-04-13	Teramo	2020-03-16	2020-03-25
Milano	2020-03-06	2020-03-20	Pescara	2020-03-11	2020-03-20
Bergamo	2020-02-27	2020-03-21	Chieti	2020-03-18	2020-04-17
Brescia	2020-03-03	2020-03-19	Campobasso	2020-03-19	2020-05-09
Pavia	2020-02-29	2020-04-05	Foggia	2020-03-16	2020-03-31
Cremona	2020-02-27	2020-03-21	Bari	2020-03-18	2020-03-29
Mantova	2020-03-07	2020-03-20	Taranto	2020-03-27	2020-04-02
Bolzano	2020-03-10	2020-03-29	Brindisi	2020-03-14	2020-04-13
Trento	2020-03-09	2020-03-21	Lecce	2020-03-21	2020-03-31
Verona	2020-03-11	2020-04-10	Potenza	2020-03-18	2020-03-20
Vicenza	2020-03-11	2020-04-03	Matera	2020-03-23	2020-03-27
Belluno	2020-03-07	2020-04-20	Cosenza	2020-03-26	2020-04-17
Treviso	2020-03-10	2020-03-21	Catanzaro	2020-03-26	2020-03-28
Venezia	2020-03-07	2020-04-08	Reggio di Calabria	2020-03-18	2020-03-28
Padova	2020-03-01	2020-03-26	Trapani	nan	2020-04-05
Rovigo	2020-03-18	2020-04-22	Palermo	2020-03-23	2020-03-23
Udine	2020-03-12	2020-04-03	Messina	2020-03-20	2020-03-27
Gorizia	2020-03-12	2020-04-22	Agrigento	2020-03-29	2020-03-30
Trieste	2020-03-07	2020-04-17	Caltanissetta	2020-03-20	2020-04-04
Piacenza	2020-02-27	2020-03-19	Enna	2020-03-18	2020-03-26
Parma	2020-02-29	2020-03-23	Catania	2020-03-21	2020-03-22
'Reggio nell''Emilia'	2020-03-07	2020-03-22	Ragusa	2020-03-26	2020-03-26
Modena	2020-03-07	2020-03-24	Siracusa	2020-03-25	2020-03-26
Bologna	2020-03-12	2020-03-28	Sassari	2020-03-14	2020-03-20
Ferrara	2020-03-16	2020-04-03	Nuoro	2020-03-10	2020-03-25
Ravenna	2020-03-12	2020-03-20	Cagliari	2020-04-03	2020-04-10
Forlì-Cesena	2020-03-12	2020-04-04	Pordenone	2020-03-12	2020-03-26
Pesaro e Urbino	2020-03-01	2020-03-14	Isernia	2020-03-27	2020-04-04
Ancona	2020-03-06	2020-03-21	Oristano	2020-04-19	2020-04-19
Macerata	2020-03-11	2020-03-23	Biella	2020-03-07	2020-03-21
Ascoli Piceno	2020-03-14	2020-03-27	Lecco	2020-03-06	2020-03-20
Massa Carrara	2020-03-06	2020-03-29	Lodi	2020-02-27	2020-03-04
Lucca	2020-03-12	2020-03-29	Rimini	2020-03-04	2020-03-22
Pistoia	2020-03-10	2020-03-19	Prato	2020-03-10	2020-03-31
Firenze	2020-03-13	2020-04-03	Crotone	2020-03-14	2020-03-20
Livorno	2020-03-13	2020-03-21	Vibo Valentia	2020-03-13	2020-03-27
Pisa	2020-03-13	2020-03-29	Verbano-Cusio-Ossola	2020-03-12	2020-04-07
Arezzo	2020-03-14	2020-03-17	Monza e della Brianza	2020-03-11	2020-03-20
Siena	2020-03-13	2020-03-29	Fermo	2020-03-13	2020-03-26
Grosseto	2020-03-13	2020-03-27	Barletta-Andria-Trani	2020-03-22	2020-04-11
			Sud Sardegna	2020-03-26	2020-03-27

Table E: **Table of epidemic features for provinces of Italy, when available.**

Province	Incidence onset	Incidence peak time	Mortality onset	Mortality peak time
Álava	2020-03-07	2020-03-25	2020-03-16	2020-03-31
Albacete	2020-03-17	2020-03-29	2020-03-17	2020-04-05
Alicante	2020-03-24	2020-03-29	2020-03-21	2020-04-03
Almería	nan	2020-03-28	2020-03-22	2020-04-10
Ávila	2020-03-18	2020-03-27	2020-03-17	2020-03-26
Badajoz	2020-03-25	2020-03-27	2020-03-24	2020-04-09
Baleares	2020-03-22	2020-03-26	2020-03-21	2020-04-01
Barcelona	2020-03-15	2020-03-25	2020-03-12	2020-03-31
Burgos	2020-03-19	2020-03-24	2020-03-16	2020-03-31
Cáceres	2020-03-19	2020-03-27	2020-03-14	2020-04-01
Cádiz	nan	2020-04-01	2020-03-27	2020-04-08
Castellón	2020-03-23	2020-03-26	2020-03-21	2020-04-08
Ciudad Real	2020-03-17	2020-04-04	2020-03-17	2020-04-09
Córdoba	2020-03-28	2020-04-04	2020-03-19	2020-03-31
A Coruña	2020-03-22	2020-04-01	2020-03-22	2020-04-01
Cuenca	2020-03-19	2020-04-08	2020-03-17	2020-03-27
Girona	2020-03-18	2020-03-25	2020-03-17	2020-04-03
Granada	2020-03-23	2020-03-30	2020-03-16	2020-03-28
Guadalajara	2020-03-16	2020-03-31	2020-03-21	2020-03-25
Guipúzcoa	2020-03-22	2020-03-25	2020-03-20	2020-04-10
Huelva	nan	2020-04-02	2020-03-27	2020-04-06
Huesca	2020-03-23	2020-04-01	2020-03-21	2020-04-09
Jaén	2020-03-23	2020-03-30	2020-03-13	2020-04-08
León	2020-03-22	2020-03-28	2020-03-16	2020-04-03
Lleida	2020-03-18	2020-03-25	2020-03-16	2020-03-26
La Rioja	2020-03-07	2020-03-27	2020-03-11	2020-04-06
Lugo	2020-03-25	2020-04-01	2020-03-23	2020-04-01
Madrid	2020-03-09	2020-03-25	2020-03-09	2020-03-27
Málaga	2020-03-24	2020-03-24	2020-03-14	2020-04-10
Murcia	2020-03-25	2020-03-25	2020-03-24	2020-04-05
Navarra	2020-03-14	2020-03-26	2020-03-15	2020-03-30
Ourense	2020-03-22	2020-04-01	2020-03-22	2020-04-01
Asturias	2020-03-18	2020-03-19	2020-03-19	2020-04-10
Palencia	2020-03-20	2020-03-27	2020-03-24	2020-04-04
Las Palmas	nan	2020-03-28	2020-03-20	2020-03-21
Pontevedra	2020-03-21	2020-04-01	2020-03-26	2020-03-31
Salamanca	2020-03-17	2020-03-28	2020-03-16	2020-03-28
Santa Cruz de Tenerife	2020-03-24	2020-03-26	2020-03-20	2020-03-21
Cantabria	2020-03-19	2020-03-26	2020-03-20	2020-03-31
Segovia	2020-03-17	2020-04-07	2020-03-16	2020-03-30
Sevilla	nan	2020-03-28	2020-03-22	2020-04-07
Soria	2020-03-17	2020-03-25	2020-03-16	2020-03-30
Tarragona	2020-03-24	2020-03-31	2020-03-21	2020-04-08
Teruel	2020-03-23	2020-03-26	2020-03-16	2020-04-01
Toledo	2020-03-17	2020-03-26	2020-03-17	2020-04-09
Valencia	2020-03-23	2020-03-24	2020-03-21	2020-04-02
Valladolid	2020-03-19	2020-04-10	2020-03-18	2020-04-01
Vizcaya	2020-03-19	2020-03-25	2020-03-17	2020-04-08
Zamora	2020-03-22	2020-04-03	2020-03-17	2020-04-03
Zaragoza	2020-03-23	2020-03-26	2020-03-10	2020-04-01
Ceuta	2020-03-30	2020-03-30	2020-03-26	2020-04-05
Melilla	2020-04-03	2020-04-03	2020-03-24	2020-03-24

Table F: **Table of epidemic features for provinces of Spain, when available.**

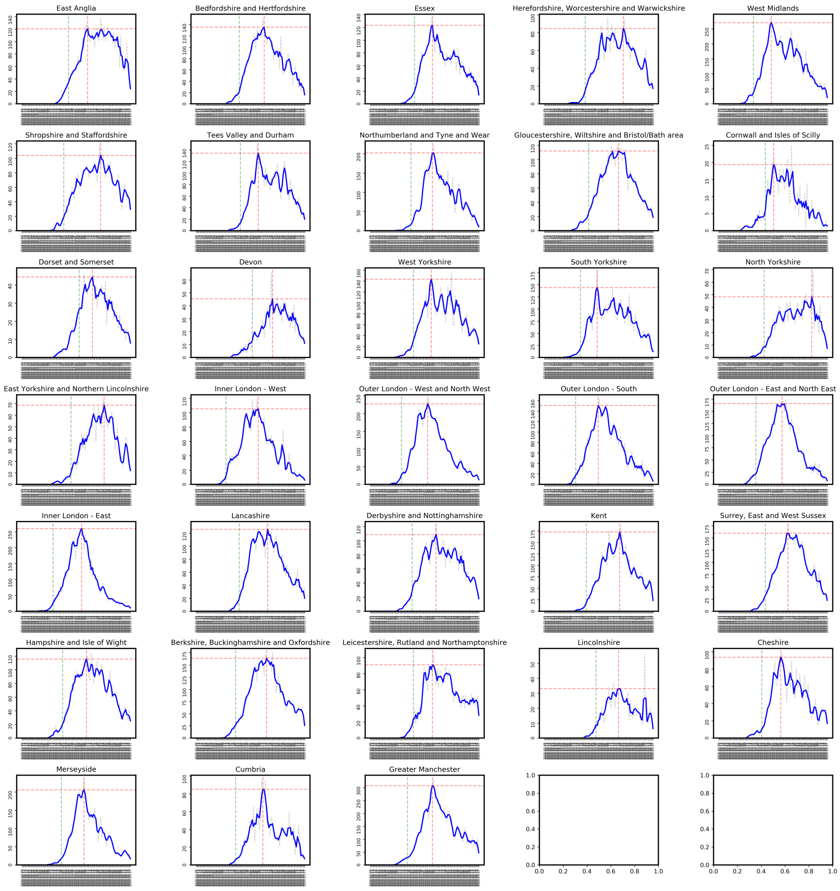

Fig D: **Epidemic curves of confirmed cases for the NUTS2 of England.** Green dashed line to represent the incidence onset, red dashed line to represent the incidence peak time.

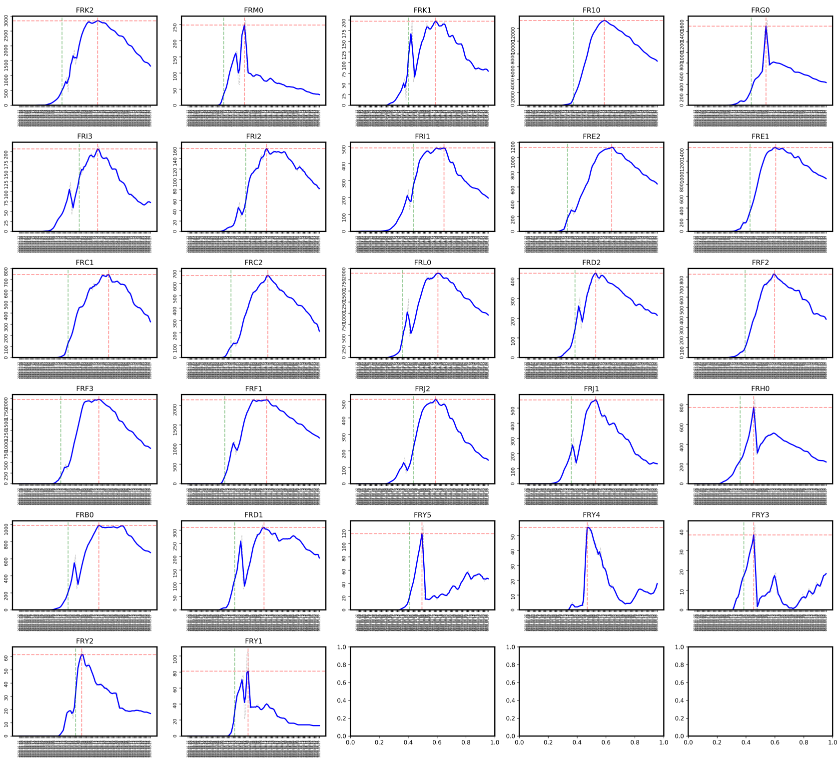

Fig E: **Epidemic curves of confirmed cases for the NUTS2 of France.** Green dashed line to represent the incidence onset, red dashed line to represent the incidence peak time.

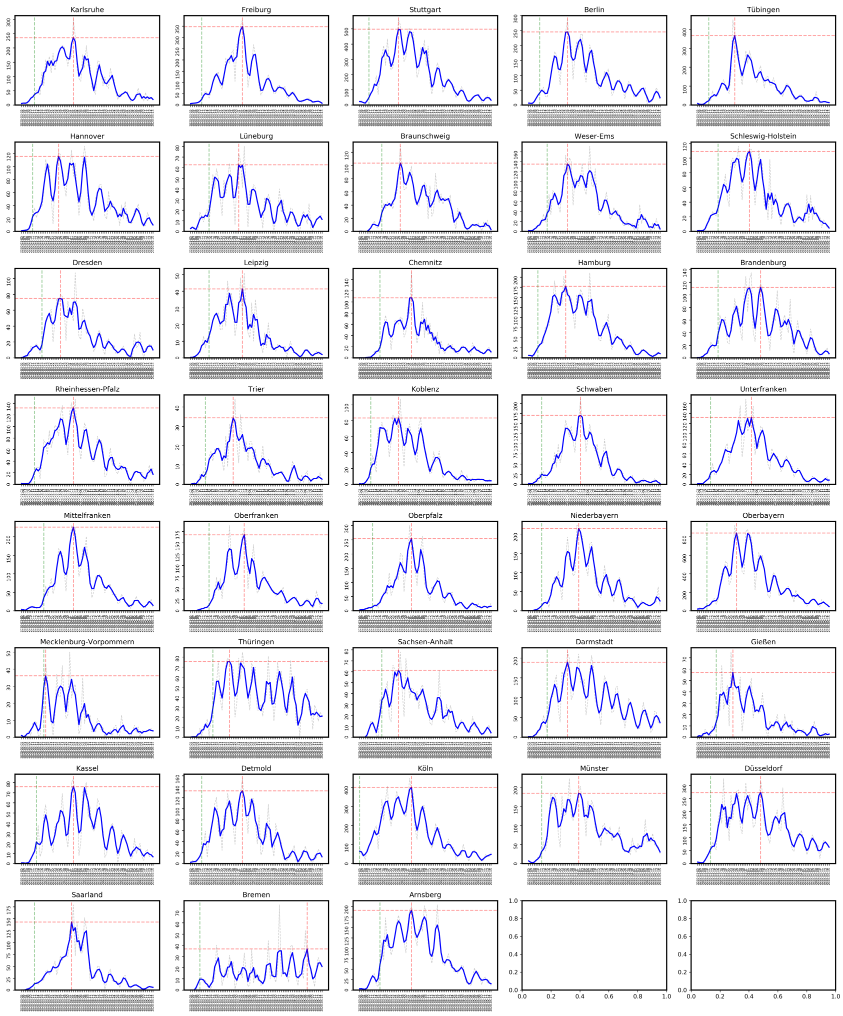

Fig F: **Epidemic curves of confirmed cases for the NUTS2 of Germany.** Green dashed line to represent the incidence onset, red dashed line to represent the incidence peak time.

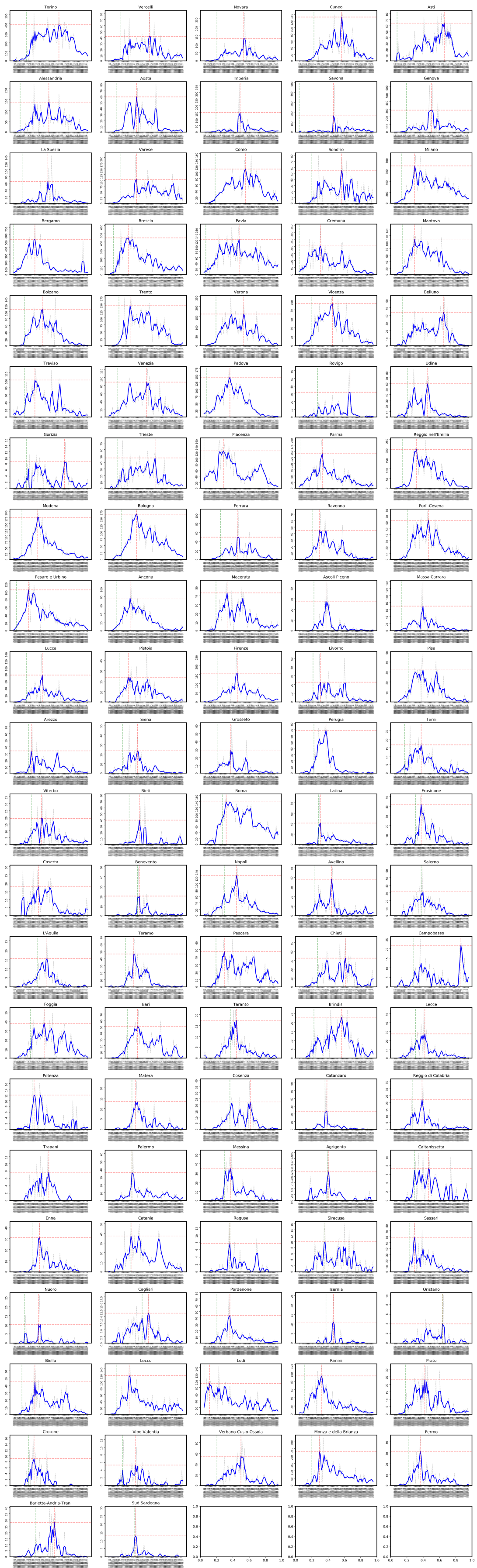

Fig G: **Epidemic curves of confirmed cases for the NUTS2 of Italy.** Green dashed line to represent the incidence onset, red dashed line to represent the incidence peak time.

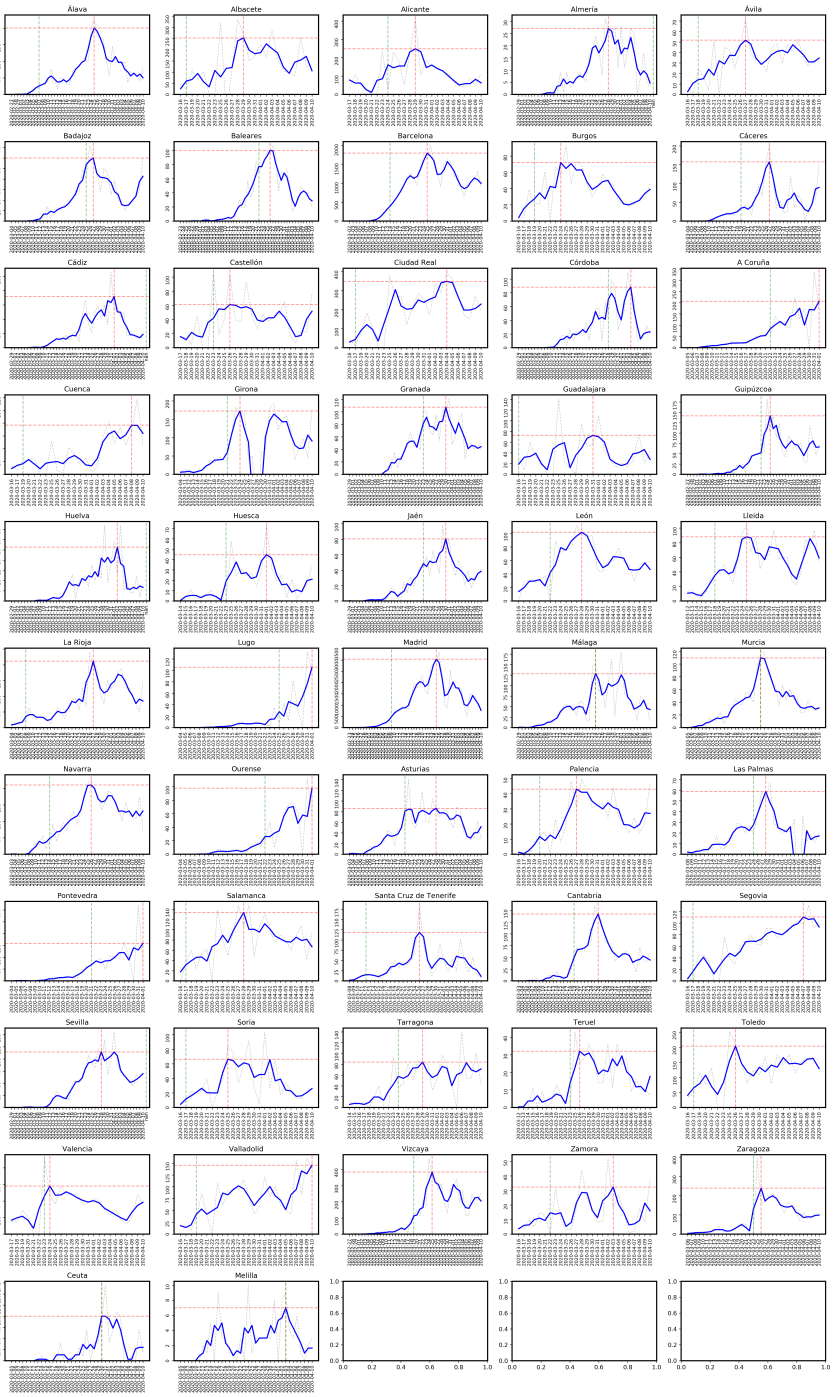

Fig H: **Epidemic curves of confirmed cases for provinces of Spain.** Green dashed line to represent the incidence onset, red dashed line to represent the incidence peak time.

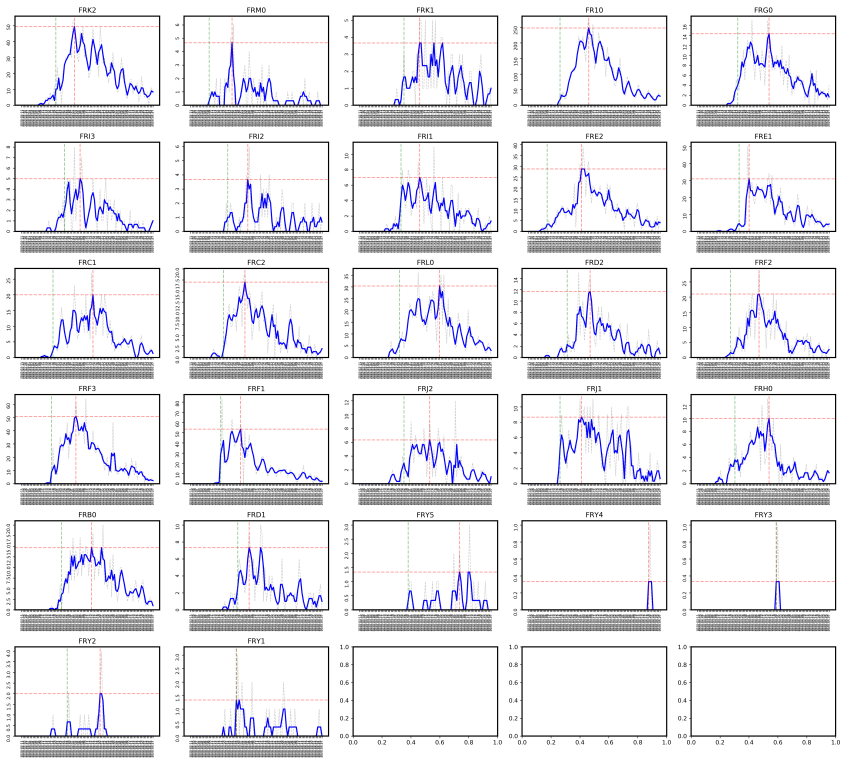

Fig I: **Epidemic curves of reported deaths for NUTS2 of France.** Green dashed line to represent the mortality onset, red dashed line to represent the mortality peak time.

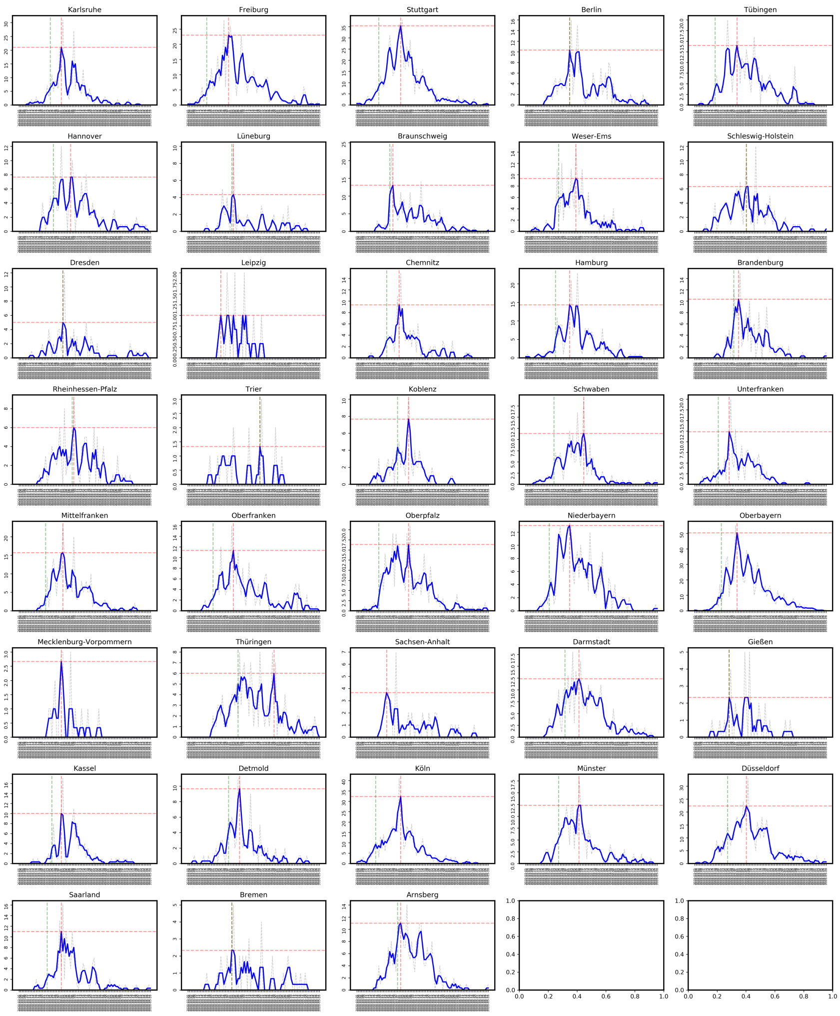

Fig J: **Epidemic curves of reported deaths for NUTS2 of Germany.** Green dashed line to represent the mortality onset, red dashed line to represent the mortality peak time.

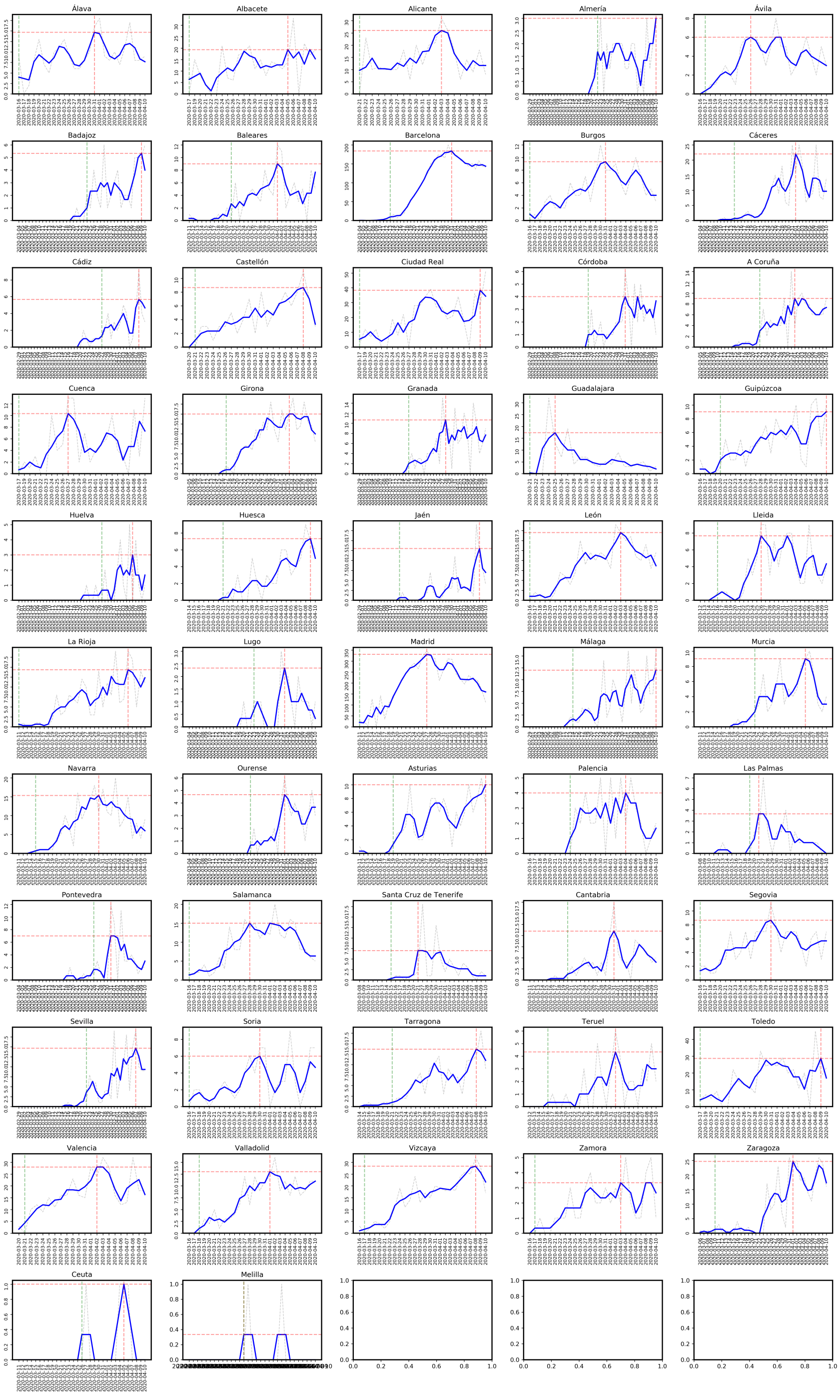

Fig K: **Epidemic curves of reported deaths for provinces of Spain.** Green dashed line to represent the mortality onset, red dashed line to represent the mortality peak time.

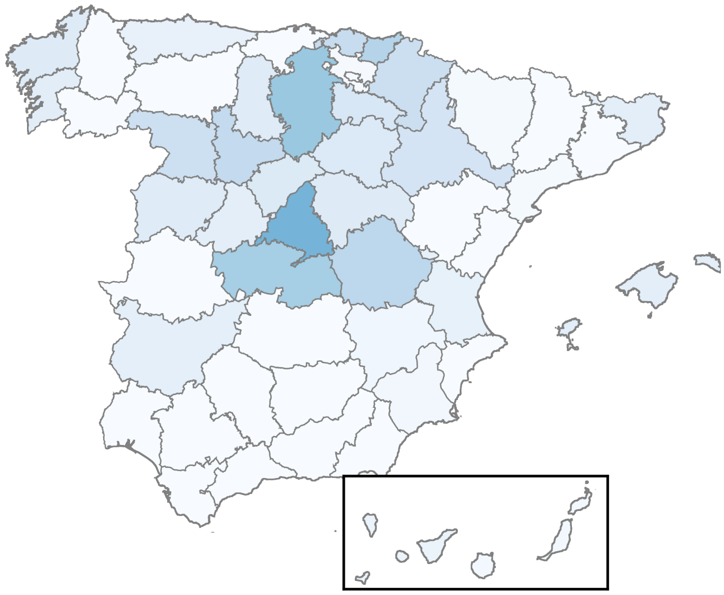

Fig L: **Corrected correlation R* for each area of origin in Spain with Cuebiq data.** The outcome scenario looks consistent with the same figure obtained from mobile phone data. Administrative boundary data were obtained from GADM for Spain (`https://gadm.org`).

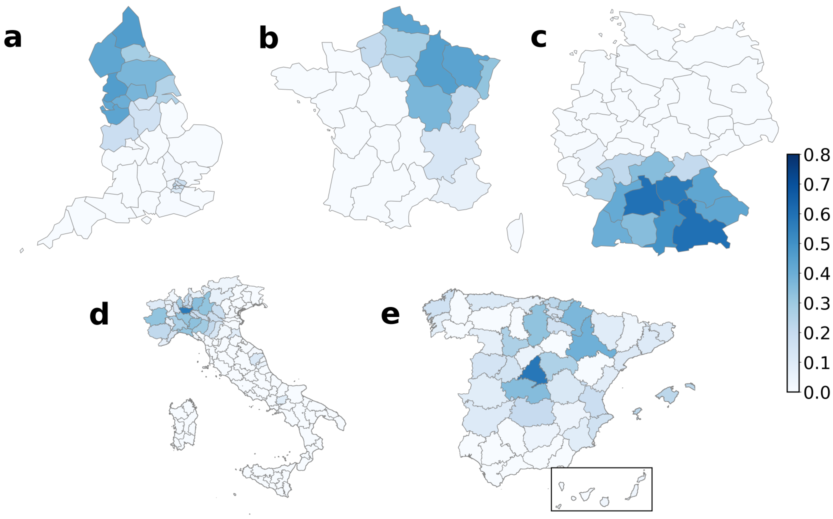

Fig M: **Origin analysis reversed map**. Conversely to the analysis in the main paper, for each destination of each country we check the corrected R-squared R* correlation of mobility and origin incidence peaks. Darker areas represent those areas where most probably the spread was originated from. Administrative boundary data were obtained from GADM for Italy and Spain (`https://gadm.org`), and from EuroStat (`https://ec.europa.eu/eurostat`) for the rest of countries.

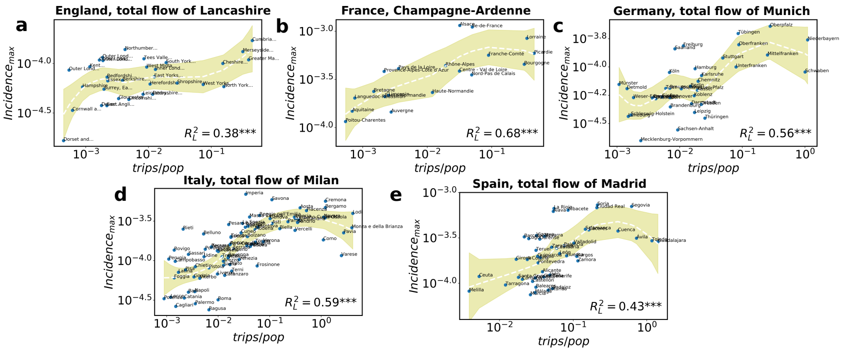

Fig N: **Correlations of incidence peaks and total flows.** Peak of incidence versus total trips per local capita received and started from **a** Lancashire, **b** Champagne-Ardenne, **c** Munich, **d** Milan, **e** Madrid during two weeks until one week before the local onset. In all cases, the curves with the fits are obtained using the non parametric LOESS method, as also the values of R_L^2. The shaded areas correspond to the 95% confidence interval.

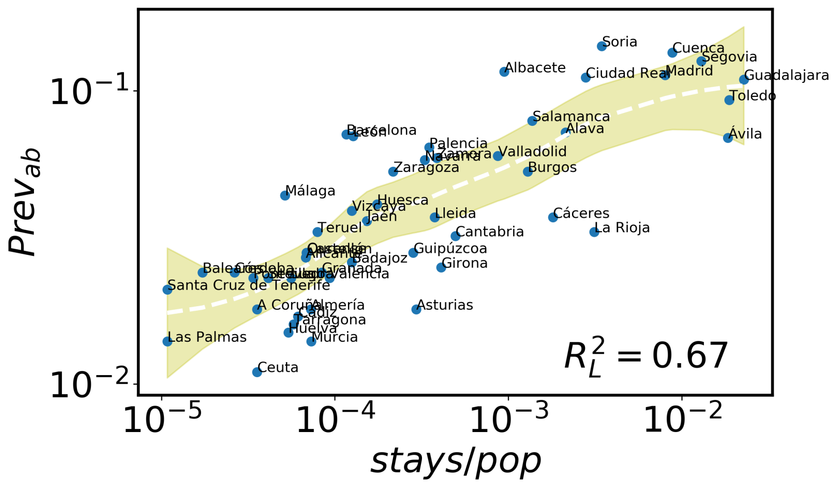

Fig O: **Stays per capita versus temporal size at May 13th 2020.** Correlation plot of stays per capita of weekenders from Madrid to other provinces versus size of prevalence in the local population.

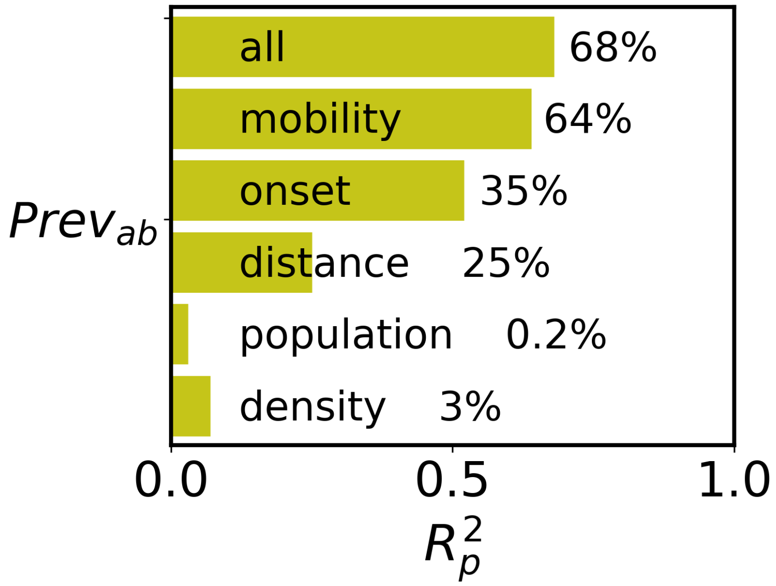

Fig P: **Correlation analysis of antibodies prevalence at May 13th 2020.** Variance of local size at May 13th 2020 explained by mobility, population, population density and distance from Madrid of each province.

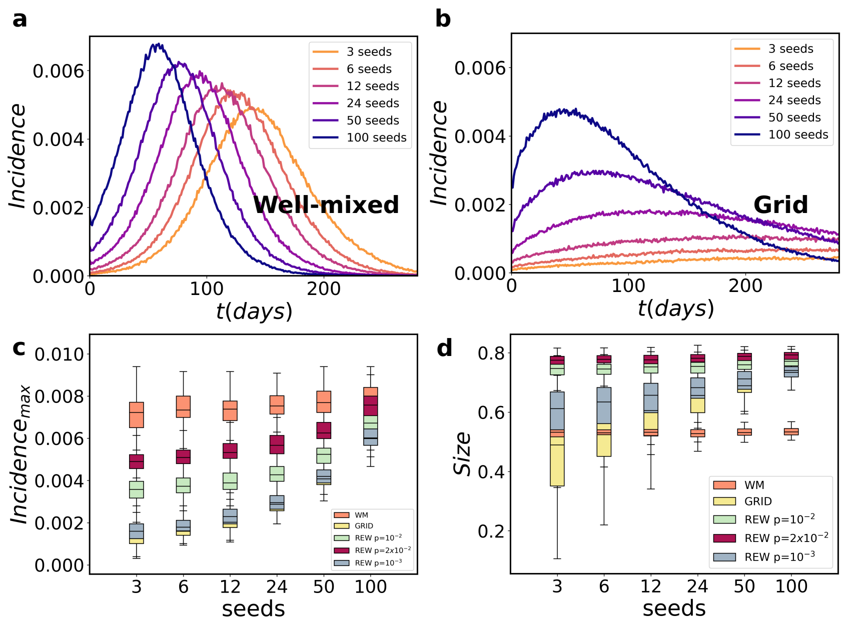

Fig Q: **Model and multi-seeding in a single population.** Average incidence curves versus number of seeds in a single population with **a** the well-mixed case and **b** the GRID topology. **c** Box-plot of the distribution of incidence peaks and **d** final epidemic sizes for a well-mixed (WM), the grid (GRID) and the rewired grid (REW) with different rewiring probability p as a function of the number of seeds. One hundred simulations have been run for each scenario. $\beta = 0.12$ days^{-1} for the well-mixed case and $\beta = 0.31$ days^{-1} for the gridded contact network.

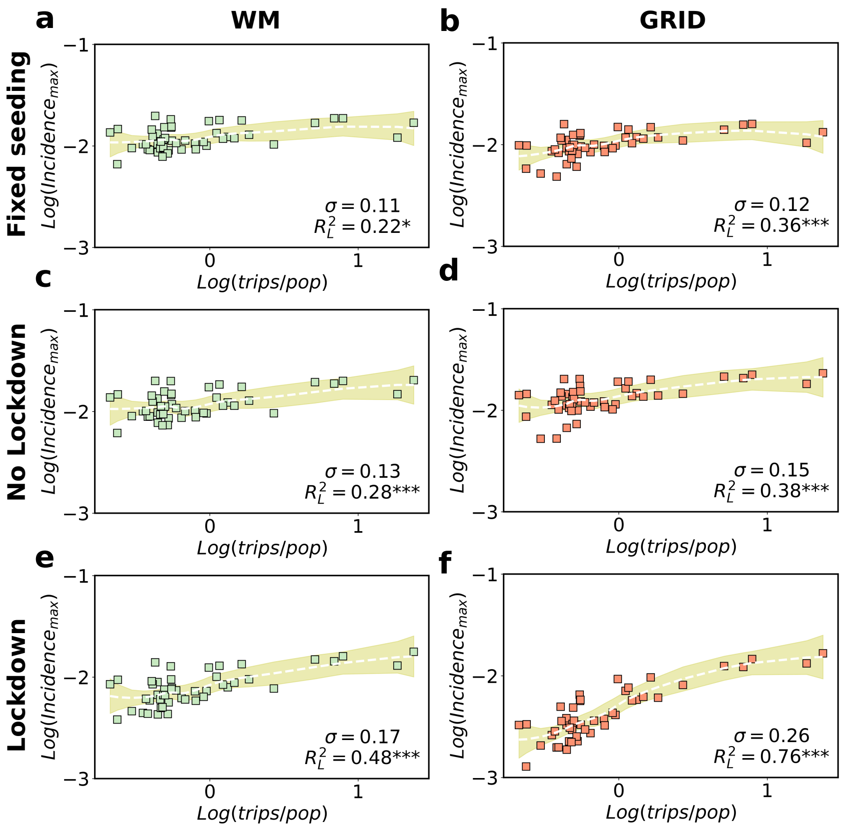

Fig R: **Models with heterogeneous populations.** Comparison of the effects of confinement policies, seeding and topology on the correlation between incidence peaks and mobility from the source (seeding) in a metapopulation model. In all the plots the height of the incidence peaks are displayed as a function of the incoming trips in every province divided by the local population. In **a**, simulation of well-mixed populations in each province allowing to travel only a fixed number of seeds from the source (Madrid). In **b**, the same for gridded contact networks in the provinces. Both scenarios are again considered in **c** and **d**, but this time without constraints in the travels between provinces and allowing thus multi-seeding. Finally, in **e** and **f**, the simulations are repeated with a national lockdown applied when Madrid arrives at 2000 cases. All results are averaged over 100 simulations with each square corresponding to the average value obtained in a province. $\beta = 0.12$ days^{-1} for the well-mixed case and $\beta = 0.31$ days^{-1} for the gridded contact network.

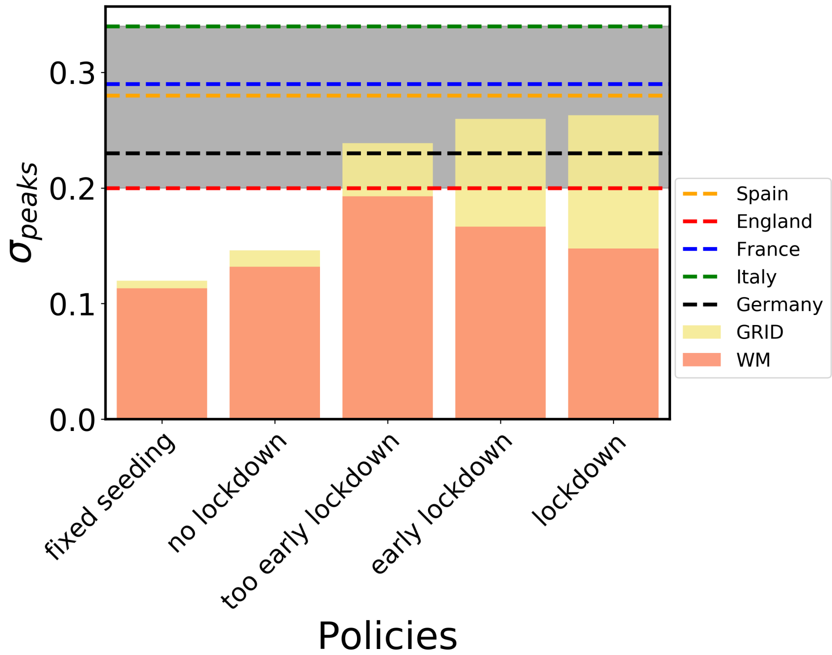

Fig S: **Policy comparison.** Incidence peaks standard deviation in for the multipopulation system with different interventions scenarios. The standard deviation is measured in plots similar to those shown in Fig. 4 both for empirical data and for the model simulations. The number of seeds in the empirical data is related to the mobility, while in the fixed seeding simulations we let each subpopulation reach a common threshold of cumulative incidence before closing the province borders. No lockdown is the scenario with no interventions. Too early, early and normal lockdown corresponds to a national lockdowns issued when Madrid (the source) reaches 1000, 2000 and 3000 total cases, respectively. After the lockdown β gets halved and all trips across borders stop. $\beta = 0.12$ days^{-1} for the well-mixed case and $\beta = 0.31$ days^{-1} for the gridded contact network.

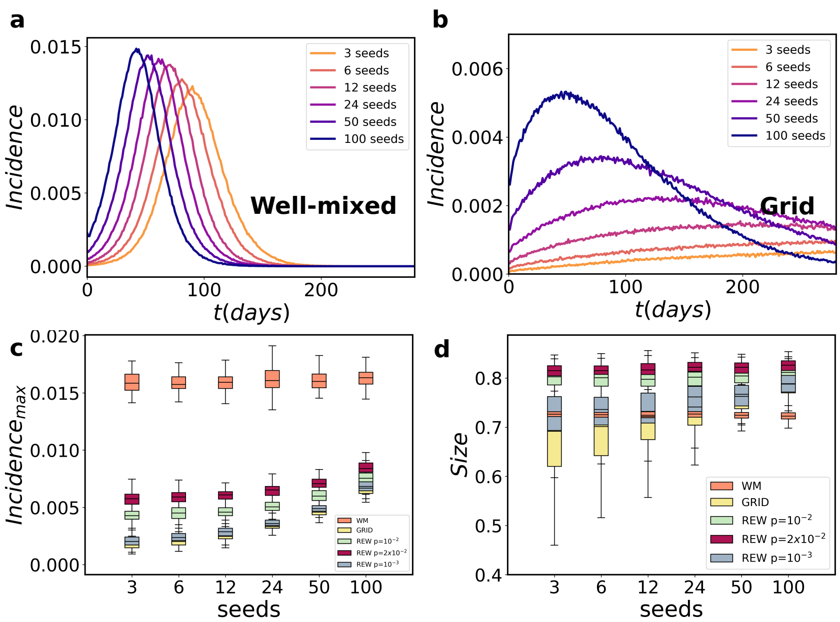

Fig T: **Model and multi-seeding in a single population.** Average incidence curves versus number of seeds in a single population with **a** the well-mixed case and **b** the GRID topology. **c** Box-plot of the distribution of incidence peaks and **d** final epidemic sizes for a well-mixed (WM), the grid (GRID) and the rewired grid (REW) with different rewiring probability p as a function of the number of seeds. One hundred simulations have been run for each scenario. $\beta = 0.15$ days^{-1} for the well-mixed case and $\beta = 0.33$ days^{-1} for the gridded contact network.

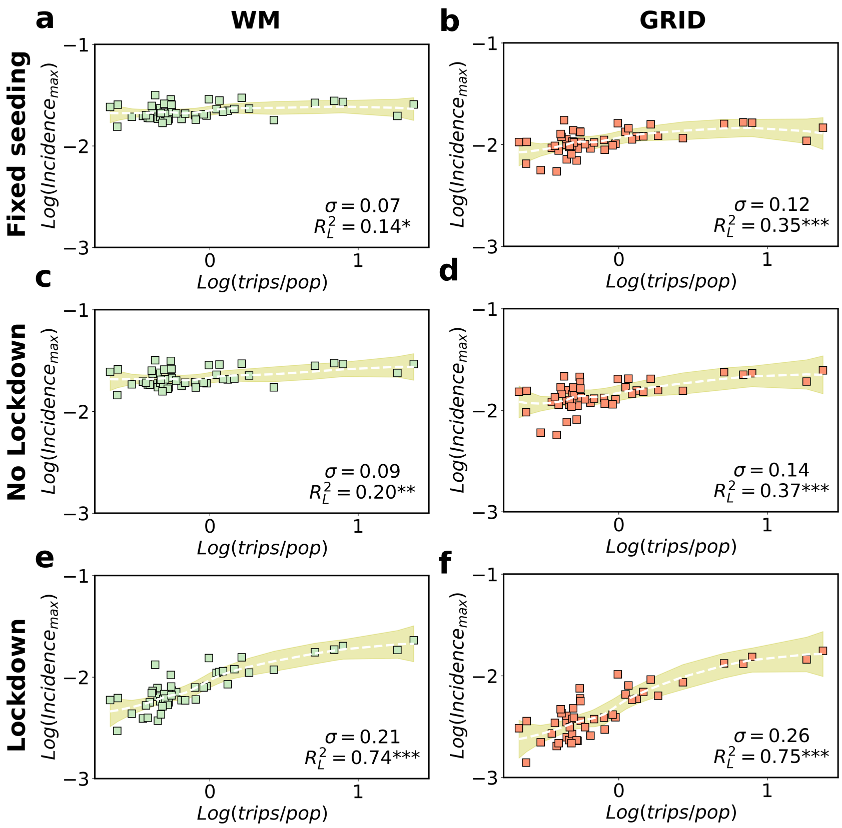

Fig U: **Models with heterogeneous populations.** Comparison of the effects of confinement policies, seeding and topology on the correlation between incidence peaks and mobility from the source (seeding) in a metapopulation model. In all the plots the height of the incidence peaks are displayed as a function of the incoming trips in every province divided by the local population. In **a**, simulation of well-mixed populations in each province allowing to travel only a fixed number of seeds from the source (Madrid). In **b**, the same for gridded contact networks in the provinces. Both scenarios are again considered in **c** and **d**, but this time without constraints in the travels between provinces and allowing thus multi-seeding. Finally, in **e** and **f**, the simulations are repeated with a national lockdown applied when Madrid arrives at 2000 cases. All results are averaged over 100 simulations with each square corresponding to the average value obtained in a province. $\beta = 0.15$ days^{-1} for the well-mixed case and $\beta = 0.33$ days^{-1} for the gridded contact network.

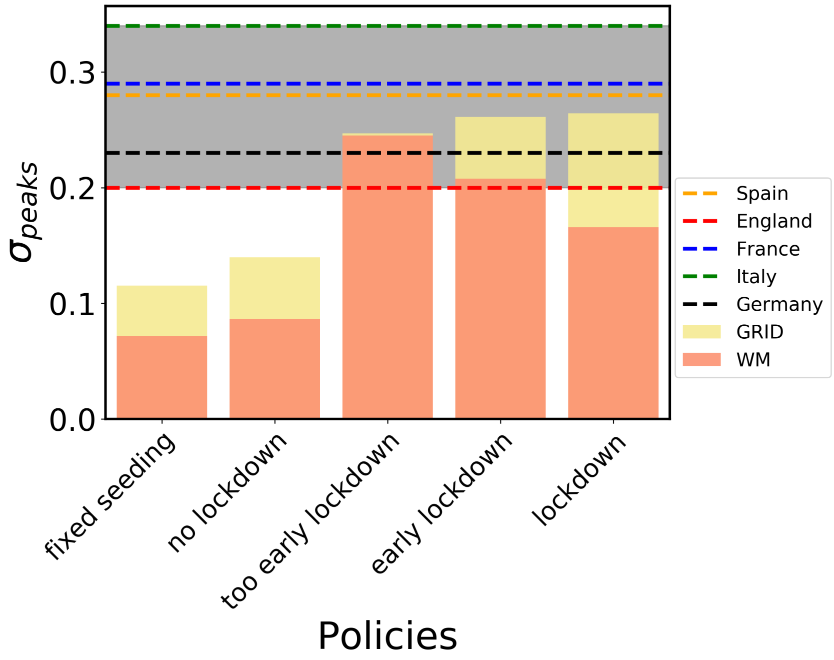

Fig V: **Policy comparison.** Incidence peaks standard deviation for the multipopulation system with different interventions scenarios. The standard deviation is measured in plots similar to those shown in Fig. 4 both for empirical data and for the model simulations. The number of seeds in the empirical data is related to the mobility, while in the fixed seeding simulations we let each subpopulation reach a common threshold of cumulative incidence before closing the province borders. No lockdown is the scenario with no interventions. Too early, early and normal lockdown corresponds to a national lockdowns issued when Madrid (the source) reaches 1000, 2000 and 3000 total cases, respectively. After the lockdown β gets halved and all trips across borders stop. $\beta = 0.15$ days^{-1} for the well-mixed case and $\beta = 0.33$ days^{-1} for the gridded contact network.

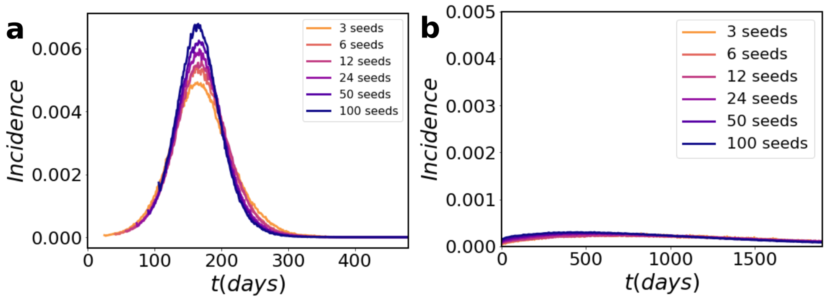

Fig W: **Collapse of the epidemic curves in a single population for lower** β**.** The collapse of the epidemic curves produced by a different number of initial seeds in a WM population in **a** and in a population with a GRID contact network in **b**. The peak time obeys to a power-law rule in the GRID scenario, while in the WM scenario it shows a logatithmic dependence on the seeds. $\beta = 0.12$ days^{-1} for the well-mixed case and $\beta = 0.31$ days^{-1} for the gridded contact network.