

Supplementary Information

Assessing geographical differences of the COVID-19 impact on fuel
consumption: the case of Italy

Section S1. Extended results for Gasoline

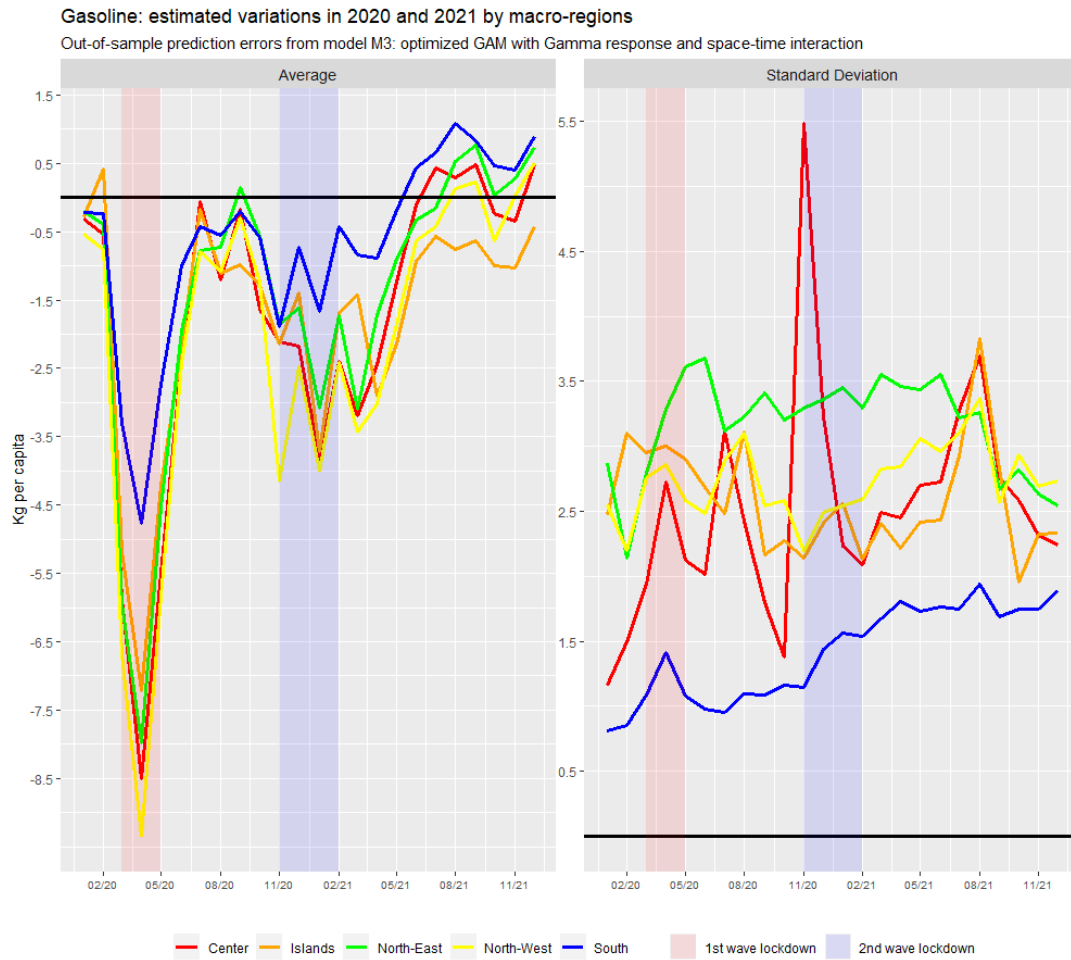


Figure S1: Estimated variations in 2020 and 2021 of per capita gasoline consumption by macro-regions. Left panel: estimated monthly average variation per macro-region. Right panel: estimated monthly standard deviation per macro-region.

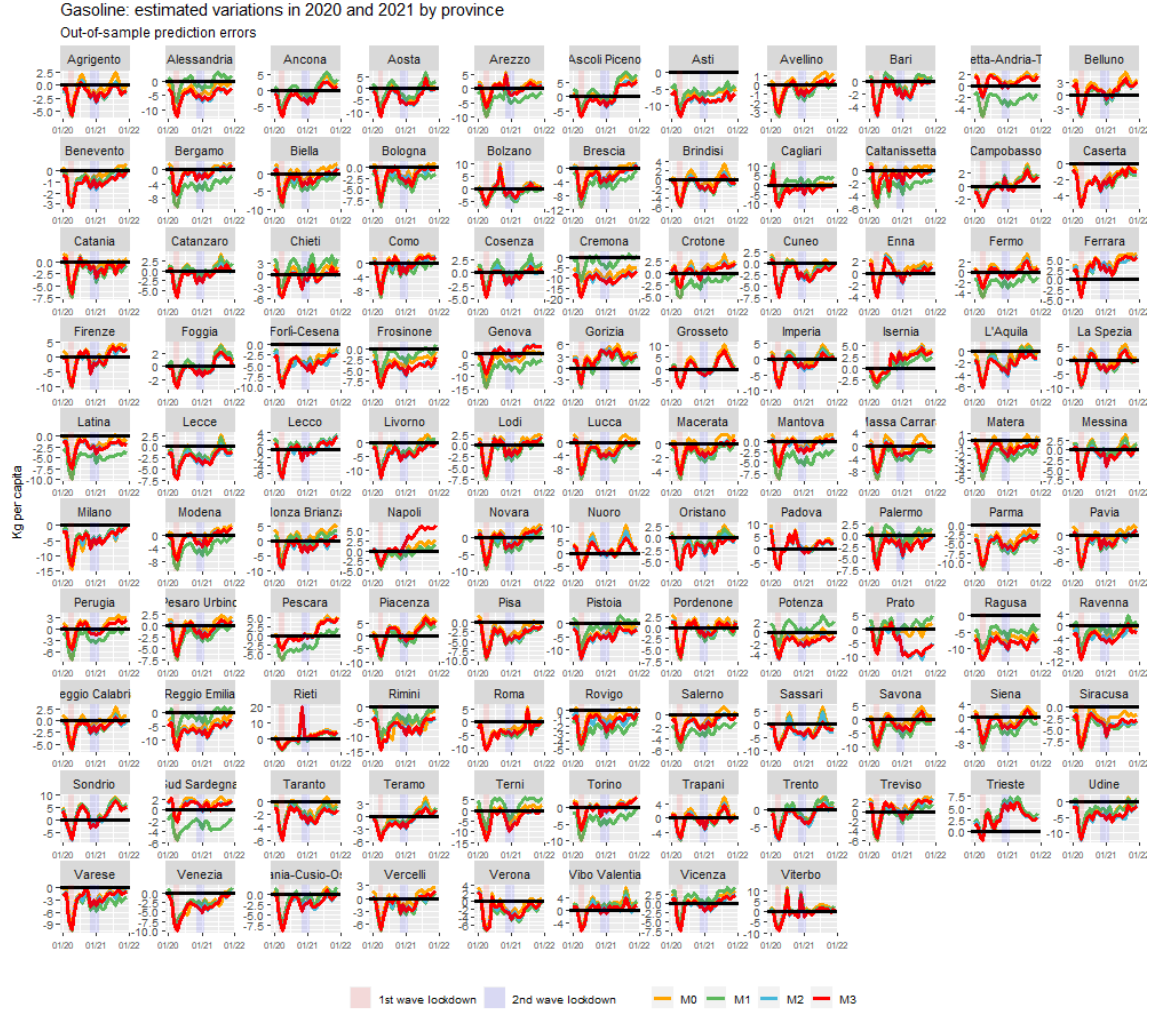


Figure S2: Time series of estimated variations in 2020 and 2021 of per capita gasoline consumption by province using Model M2. Yellow, orange and red lines correspond to model M0, M1 and M2, respectively.

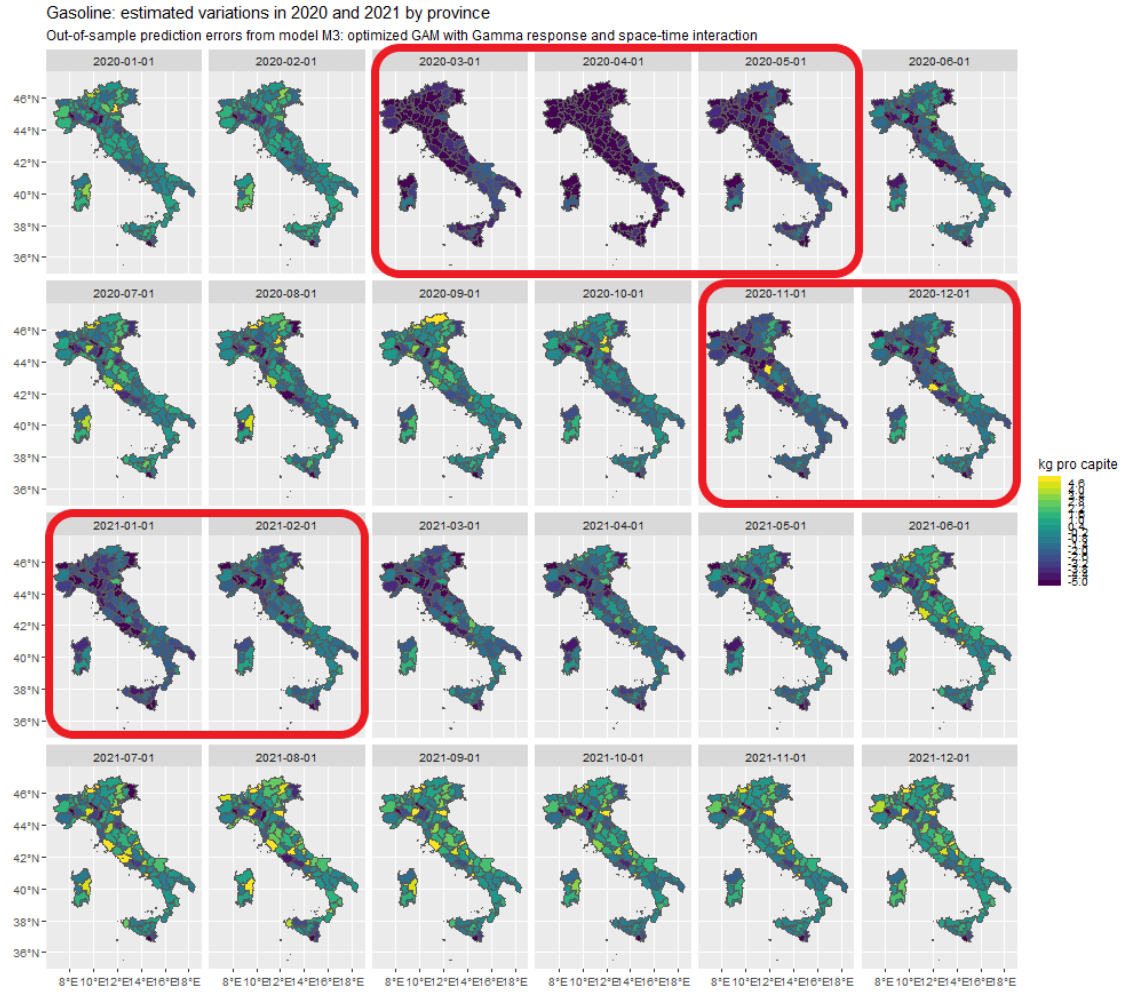


Figure S3: Maps of estimated variations (out-of-sample prediction errors) of per capita gasoline consumption in 2020 and 2021 by province. Estimates are computed using Model M2.



Figure S4: Time series of observed (black solid lines) and estimated (red, orange and yellow solid lines) per capita gasoline consumption in 2020 and 2021 by province. Yellow, orange and red lines correspond to model M0, M1 and M2, respectively.

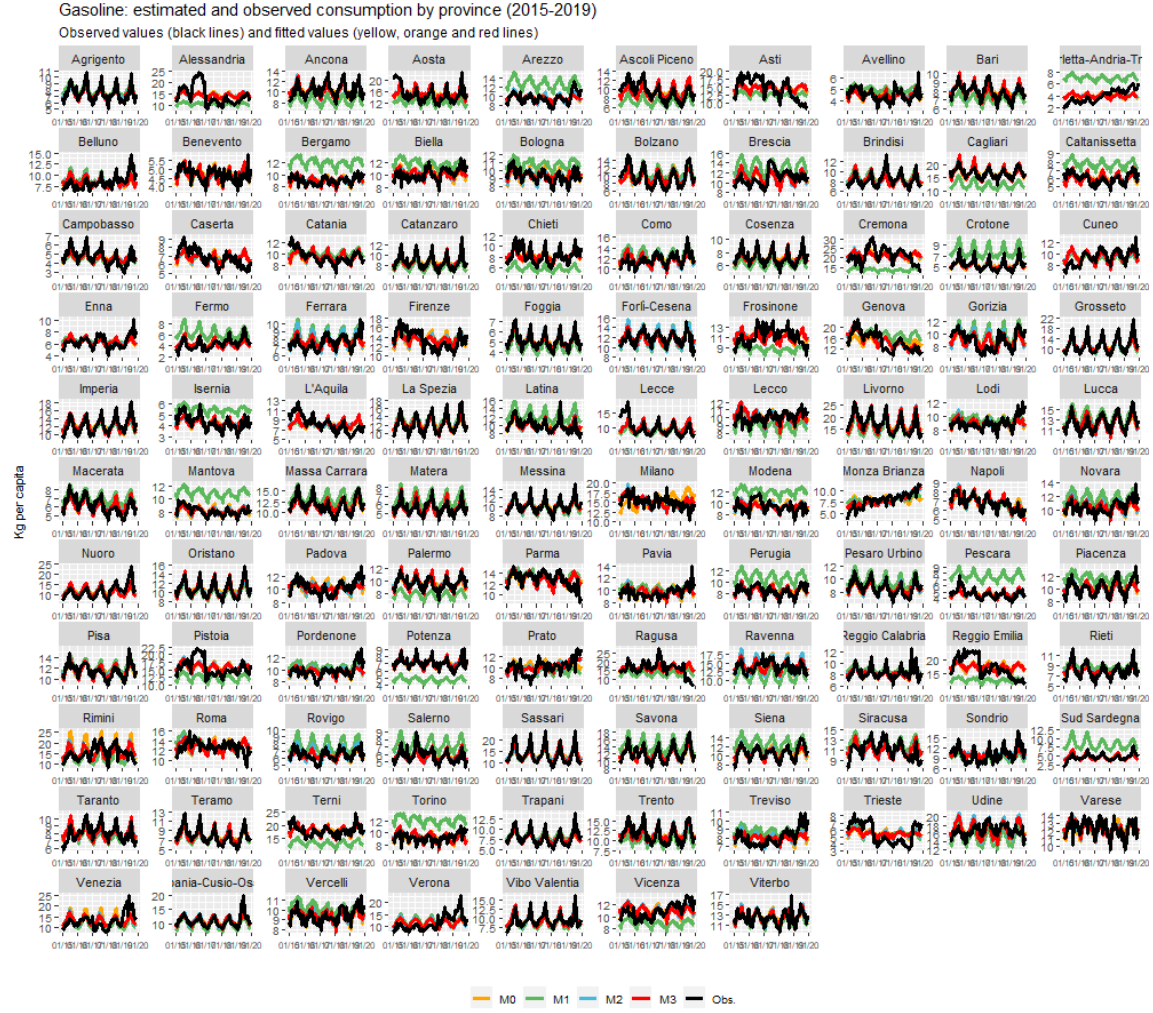


Figure S5: Time series of observed (black solid lines) and estimated (red, orange and yellow solid lines) per capita gasoline consumption during the training period (2015-2019) by province. Yellow, orange and red lines correspond to model M0, M1 and M2, respectively.

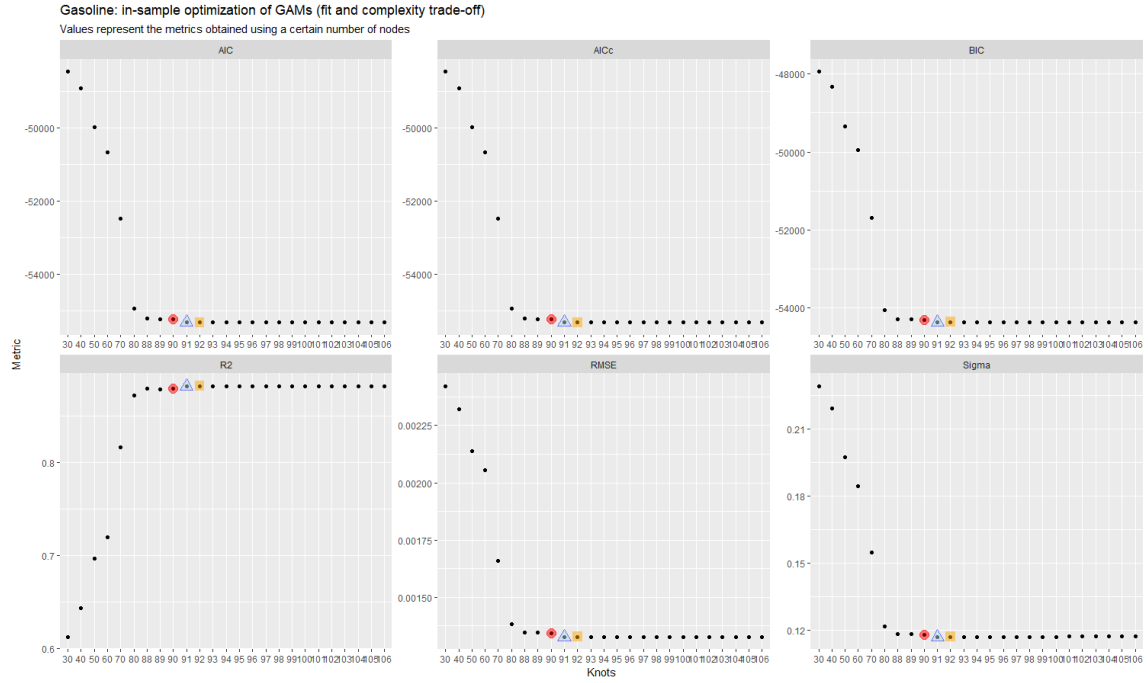


Figure S6: Gasoline (M2): in-sample accuracy metrics computed for growing number of nodes k of the Duchon bivariate spline (spatial smooth). Values are computed aggregating prediction errors from 2015 to 2018.

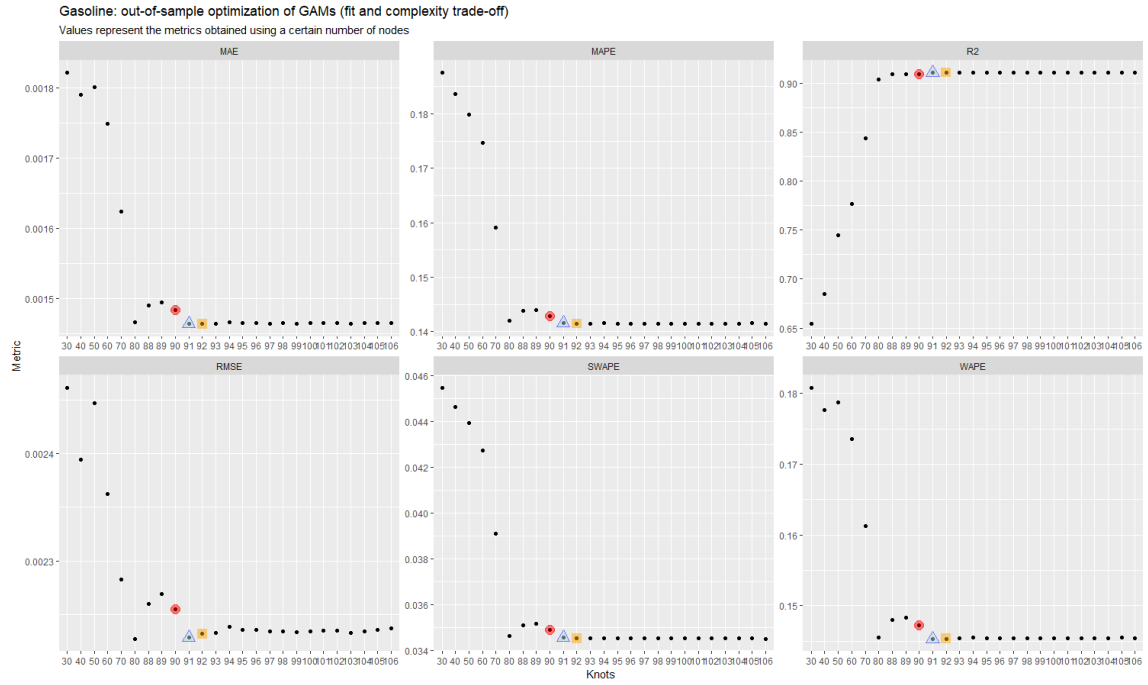


Figure S7: Gasoline (M2): out-of-sample accuracy metrics computed for growing number of nodes k of the Duchon bivariate spline (spatial smooth). Values are computed aggregating prediction errors just for 2019.

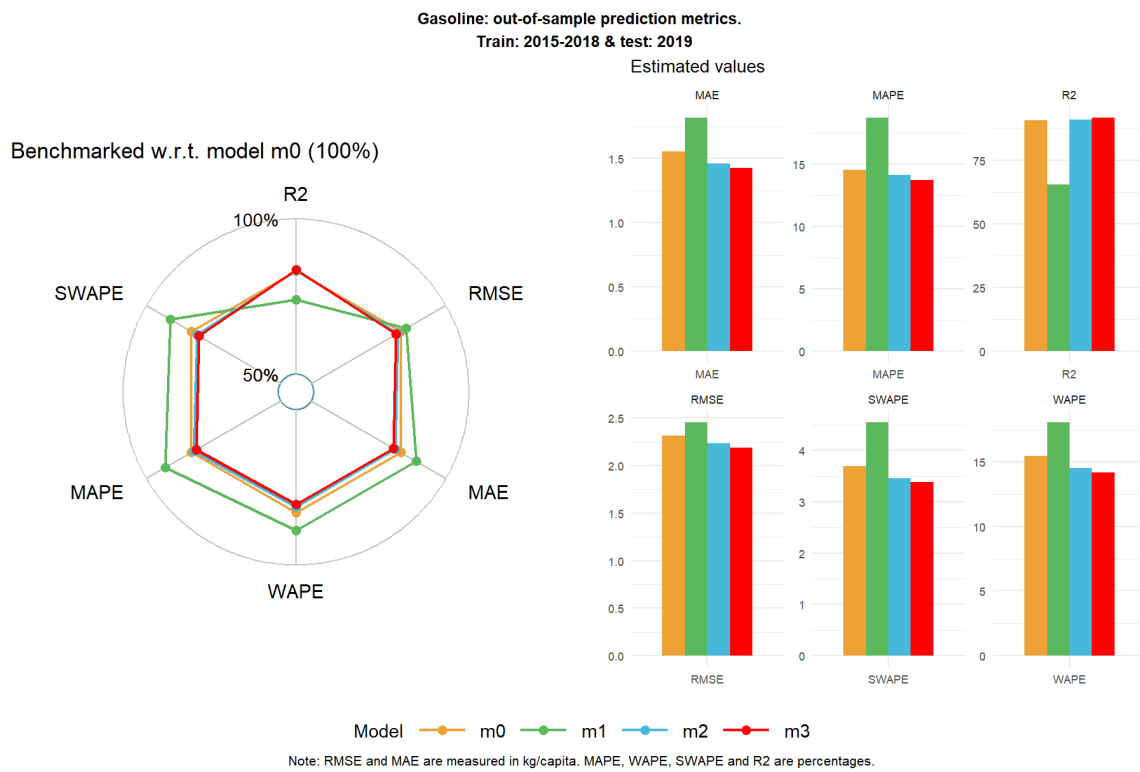


Figure S8: Gasoline: out-of-sample prediction metrics computed using 2019 as test set and 2015-2018 as training set.

Gasoline: pairwise Diebold-Mariano test with right-side alternative hypothesis

H0: the two models have the same forecast accuracy
H1: model 2 (right) is more accurate than model 1 (left).
Solid black line is 5%, while solid grey line is 1%.

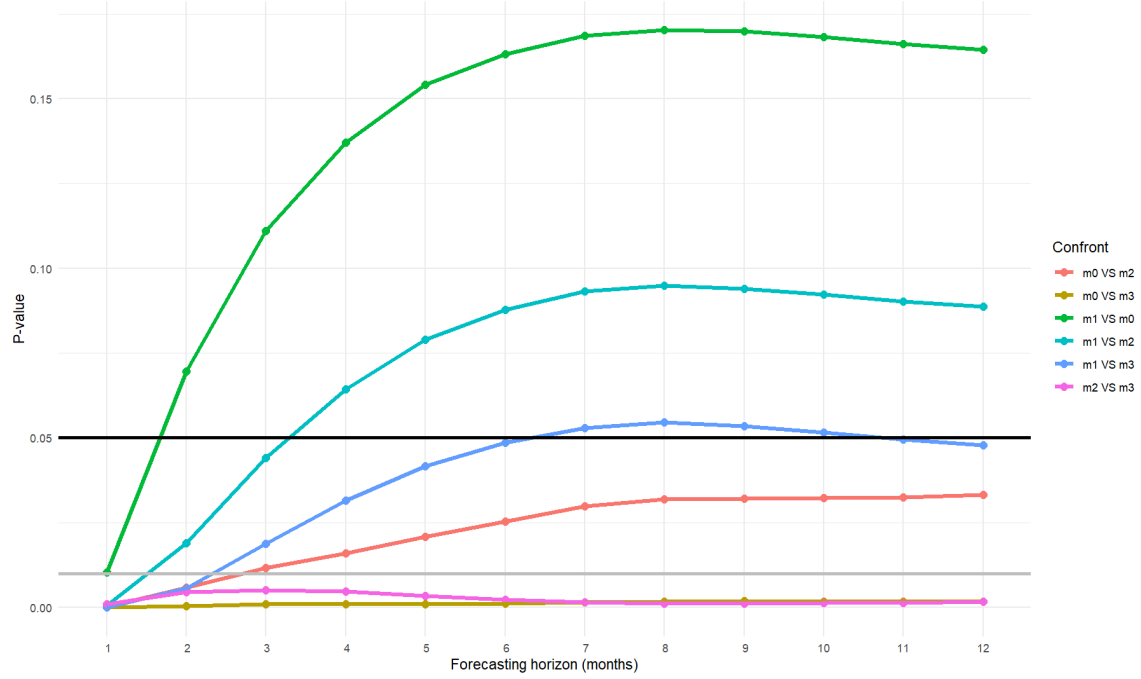


Figure S9: Gasoline: pairwise Diebold-Mariano test with right-side alternative hypothesis computed using 2019 as test set and 2015-2018 as training set.

	m0: GLM	m1: GAM	m2: optimal GAM	m3: opt. GAM with ST interaction
(Intercept)	9.55*** (2.54)	-4.80*** (0.03)	-16.44 (14.46)	-17.32 (14.08)
Month = February	-0.04*** (0.01)			
Month = March	0.10*** (0.01)			
Month = April	0.11*** (0.01)			
Month = May	0.13*** (0.02)			
Month = June	0.14*** (0.02)			
Month = July	0.14*** (0.02)			
Month = August	0.15*** (0.02)			
Month = September	0.10*** (0.02)			
Month = October	0.13*** (0.01)			
Month = November	0.03** (0.01)			
Month = December	0.12*** (0.01)			
Year	-0.01*** (0.00)			
Tourists.stays.pc	0.04*** (0.00)			
HDD	-0.00 (0.00)			
CDD	0.00*** (0.00)			
Density	0.00*** (0.00)			
Surface	0.00***			
UrbDegree = predominantly urban	-0.26 (0.15)	-0.06*** (0.01)	-9.89*** (1.06)	-9.68*** (1.03)
UrbDegree = predominantly rural	0.63*** (0.04)	-0.03 (0.01)	-4.91*** (1.33)	-4.80*** (1.30)
Border = Other regions	-0.99*** (0.18)	0.04 (0.02)	2.44*** (0.30)	2.40*** (0.29)
Coastal = on coast	0.68*** (0.15)	0.08*** (0.02)	8.82 (14.52)	9.74 (14.14)
Coastal = non-coastal	0.43*** (0.04)	0.19*** (0.02)	24.30 (14.98)	25.03 (14.59)
Non metropolitan	0.02 (0.03)	0.03* (0.01)	-1.12*** (0.33)	-1.07*** (0.32)
s(Month)		9.81*** (10.00)	9.95*** (10.00)	9.99*** (10.00)
s(Year)		3.06*** (3.54)	3.44*** (3.82)	3.31*** (3.74)
s(Tourists.stays.pc)		7.59*** (8.05)	8.59*** (8.86)	7.04*** (7.70)
s(CDD)		1.59 (1.97)	2.48*** (3.10)	1.00 (1.00)
s(HDD)		3.02** (3.80)	4.16*** (5.08)	7.50*** (8.02)
s(Density)		9.00*** (9.00)	8.82*** (8.96)	8.81*** (8.96)
s(Surface)		8.94*** (9.00)	7.43*** (7.74)	7.44*** (7.75)
s(long,lat)		29.66*** (30.00)	90.99*** (91.00)	90.99*** (91.00)
ti(long,lat,Month)				96.42*** (190.00)
AIC	-67443.36	-60623.82	-67783.20	-68136.91
BIC	-66604.23	-60077.97	-66809.62	-66509.37
Log Likelihood	33845.68	30392.57	34035.47	34308.96
Deviance	112.76	328.26	106.24	97.53
Num. smooth terms		8	8	9

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$

Table S1: Gasoline: estimated models using training data from January 2015 to December 2019

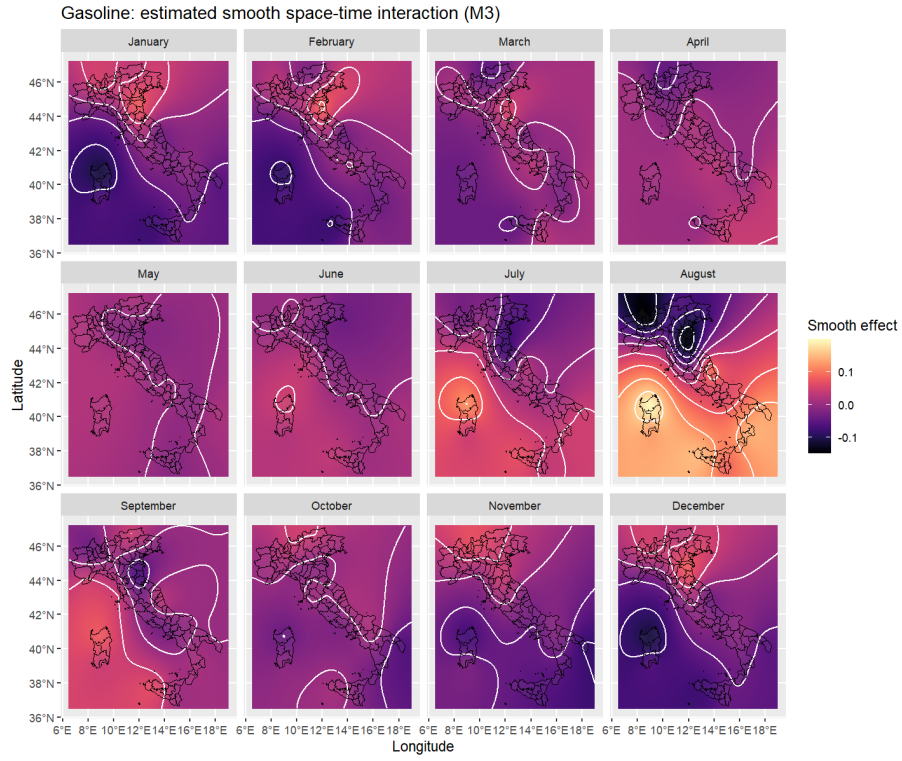


Figure S10: Gasoline: estimated monthly smooth spatial surface (M3).

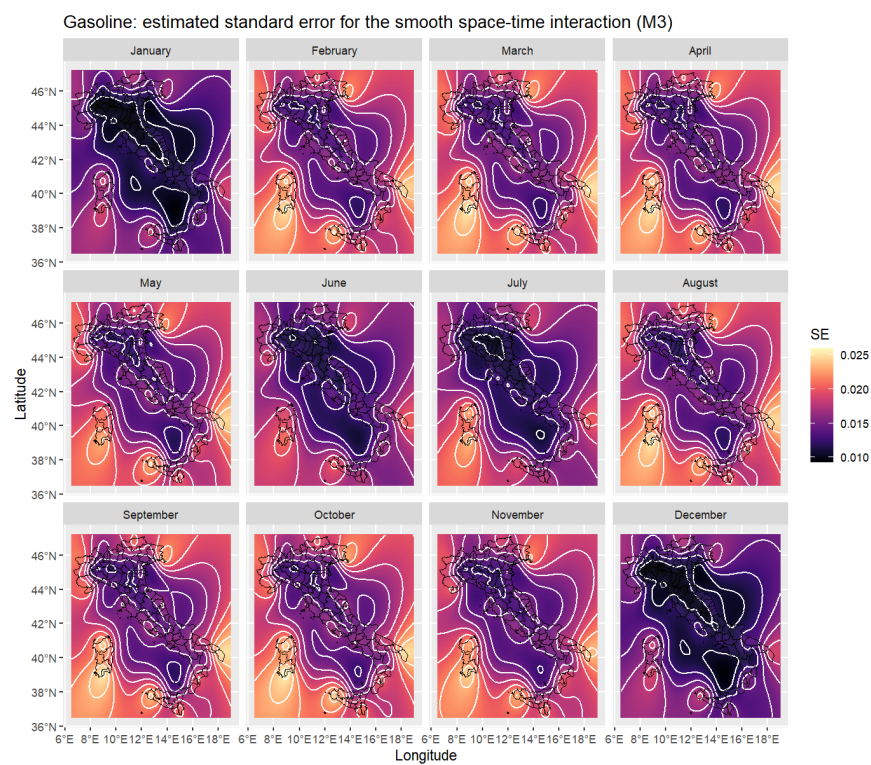


Figure S11: Gasoline: estimated standard error for the smooth space-time interaction (M3).

Gasoline: (dis)similarity measures for out-of-sample residuals by macro-regions

	Corr. in 2020 and 2021					Corr. in 2020					Corr. in 2021					Var. corr. from 2020 to 2021				
South	0.96	0.91	0.96	0.97	1	0.97	0.98	0.98	0.99	1	0.98	0.92	0.95	0.98	1	0	-0.06	-0.03	-0.02	0
North-West	0.98	0.94	0.98	1	0.97	0.98	0.97	0.98	1	0.99	0.98	0.87	0.98	1	0.98	0	-0.11	0	0	-0.02
North-East	0.98	0.93	1	0.98	0.96	0.99	0.97	1	0.98	0.98	0.97	0.78	1	0.98	0.95	-0.01	-0.19	0	0	-0.03
Islands	0.94	1	0.93	0.94	0.91	0.98	1	0.97	0.97	0.98	0.85	1	0.78	0.87	0.92	-0.13	0	-0.19	-0.11	-0.06
Center	1	0.94	0.98	0.98	0.96	1	0.98	0.99	0.98	0.97	1	0.85	0.97	0.98	0.98	0	-0.13	-0.01	0	0
	Cos. dist. in 2020 and 2021					Cos. dist. in 2020					Cos. dist. in 2021					Var. cos. dist. from 2020 to 2021				
South	0.95	0.88	0.96	0.94	1	0.99	0.99	0.99	1	1	0.76	0.45	0.8	0.69	1	-0.22	-0.54	-0.19	-0.31	0
North-West	0.99	0.97	0.98	1	0.94	0.99	0.99	0.99	1	1	0.98	0.91	0.97	1	0.69	-0.01	-0.08	-0.02	0	-0.31
North-East	0.99	0.94	1	0.98	0.96	0.99	0.98	1	0.99	0.99	0.97	0.78	1	0.97	0.8	-0.02	-0.2	0	-0.02	-0.19
Islands	0.96	1	0.94	0.97	0.88	0.99	1	0.98	0.99	0.99	0.86	1	0.78	0.91	0.45	-0.13	0	-0.2	-0.08	-0.54
Center	1	0.96	0.99	0.99	0.95	1	0.99	0.99	0.99	0.99	1	0.86	0.97	0.98	0.76	0	-0.13	-0.02	-0.01	-0.22
	Eucl. dist. in 2020 and 2021					Eucl. dist. in 2020					Eucl. dist. in 2021					Var. Eucl. dist. from 2020 to 2021				
South	7.34	6.67	5.85	9.06	0	5.83	3.94	4.74	7.32	0	4.46	5.38	3.43	5.34	0	-1.37	1.43	-1.32	-1.98	0
North-West	2.95	5.04	4.06	0	9.06	2.56	4.12	3.37	0	7.32	1.48	2.91	2.27	0	5.34	-1.08	-1.22	-1.1	0	-1.98
North-East	2.54	4.33	0	4.06	5.85	1.94	2.1	0	3.37	4.74	1.64	3.78	0	2.27	3.43	-0.29	1.68	0	-1.1	-1.32
Islands	4.09	0	4.33	5.04	6.67	2.48	0	2.1	4.12	3.94	3.25	0	3.78	2.91	5.38	0.76	0	1.68	-1.22	1.43
Center	0	4.09	2.54	2.95	7.34	0	2.48	1.94	2.56	5.83	0	3.25	1.64	1.48	4.46	0	0.76	-0.29	-1.08	-1.37
Center	Islands	North-East	North-West	South		Center	Islands	North-East	North-West	South	Center	Islands	North-East	North-West	South	Center	Islands	North-East	North-West	South

Figure S12: Gasoline: (dis)similarity measures for out-of-sample residuals by macro-regions.

Section S2. Extended results for Diesel

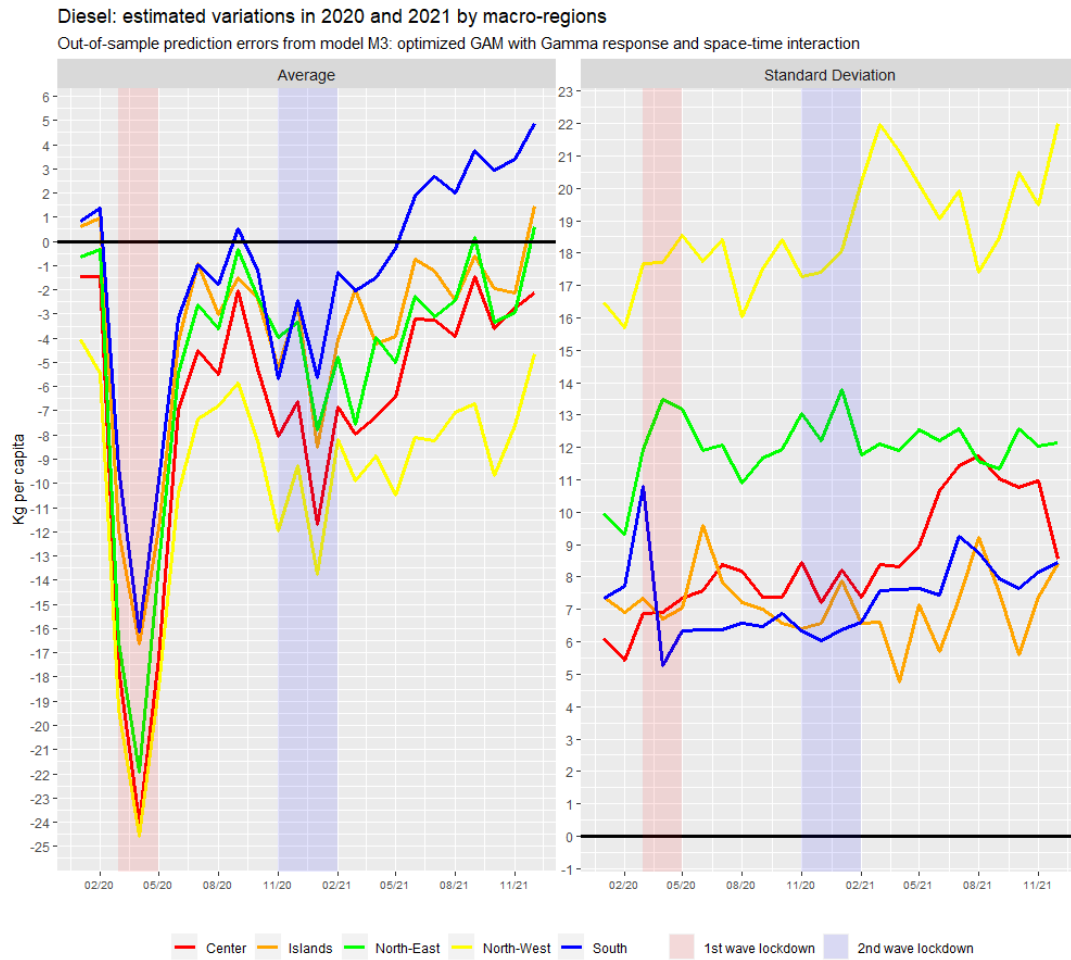


Figure S13: Estimated variations in 2020 and 2021 of per capita diesel consumption by macro-regions. Left panel: estimated monthly average variation per macro-region. Right panel: estimated monthly standard deviation per macro-region.

Diesel: estimated variations in 2020 and 2021 by province

Out-of-sample prediction errors

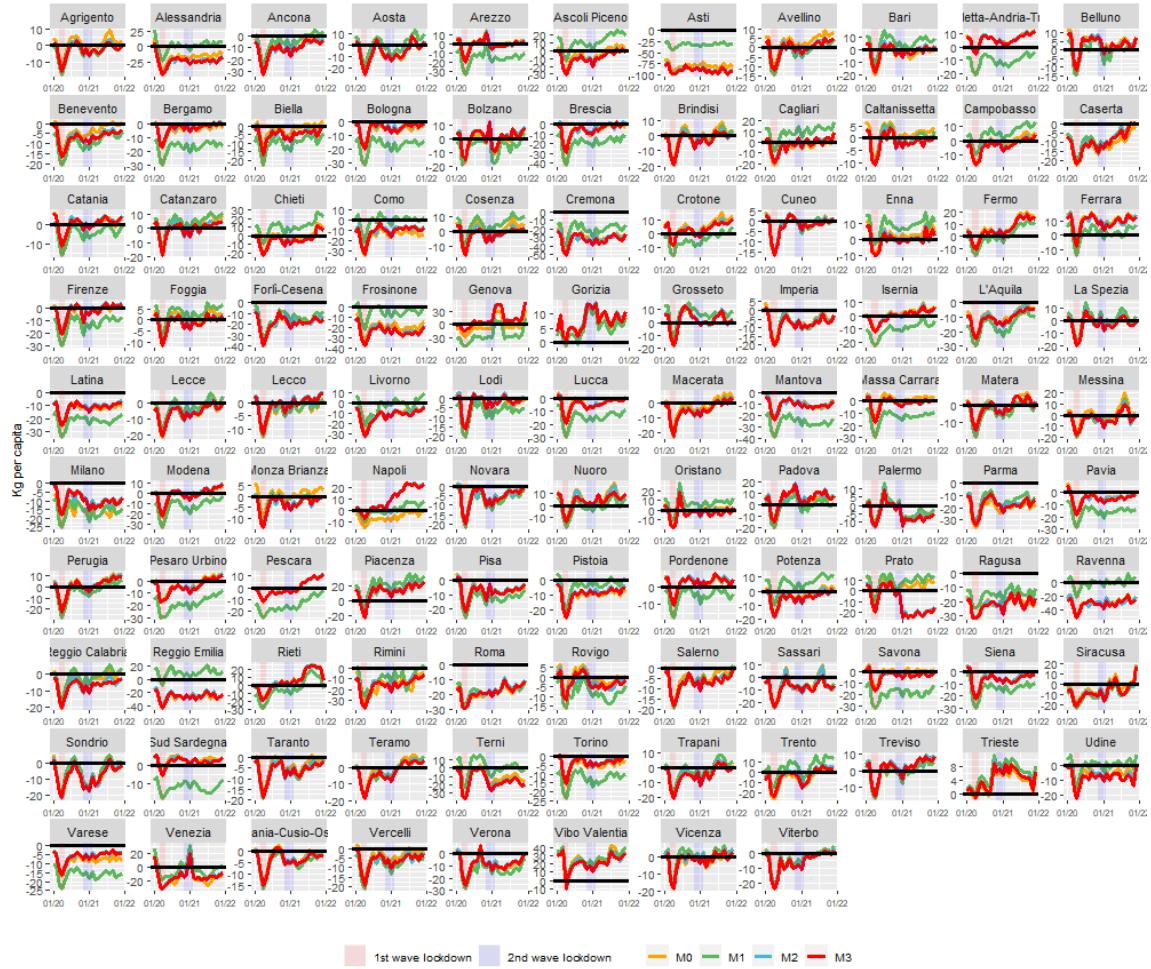


Figure S14: Time series of estimated variations in 2020 and 2021 of per capita diesel consumption by province.

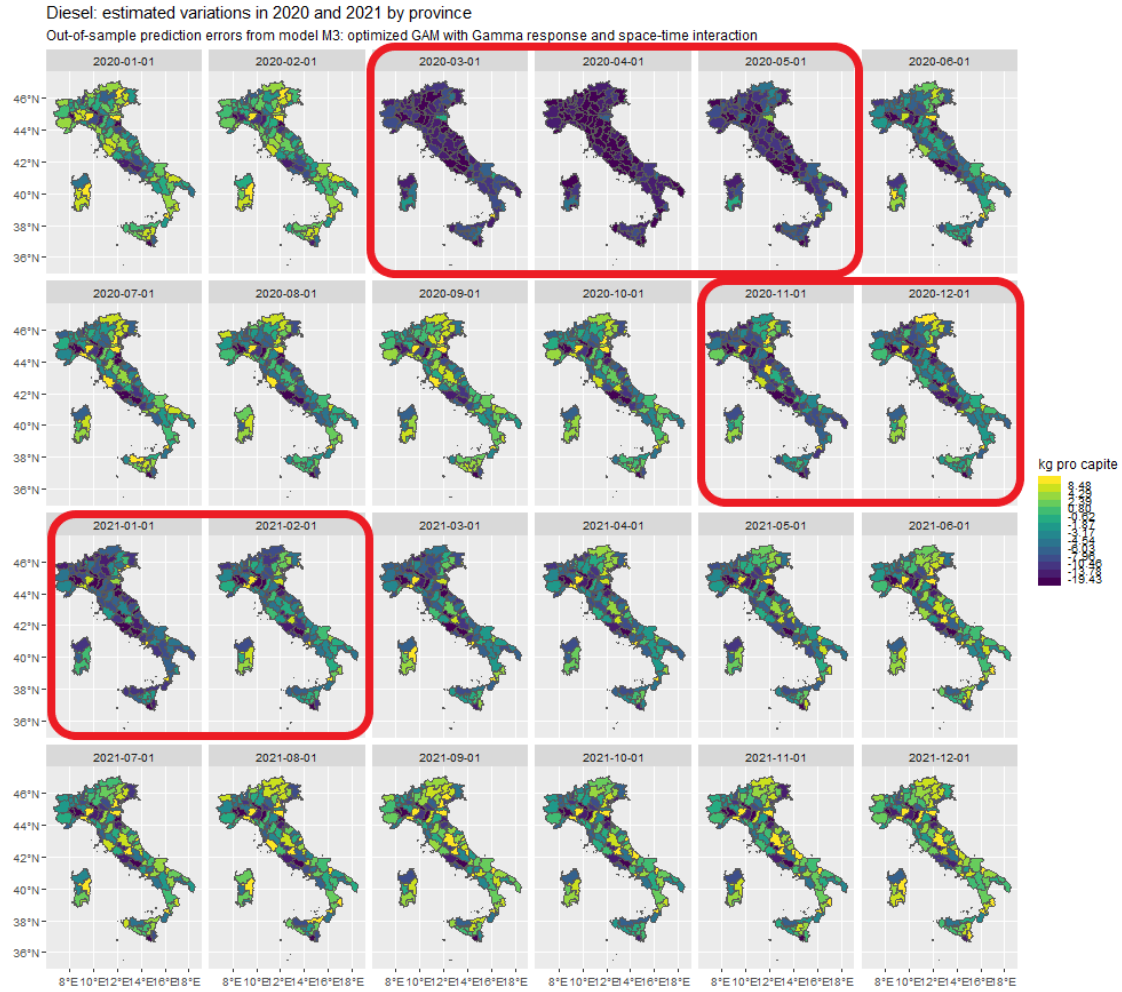


Figure S15: Maps of estimated variations (out-of-sample prediction errors) of per capita diesel consumption in 2020 and 2021 by provinces. Estimates are computed using Model M2.

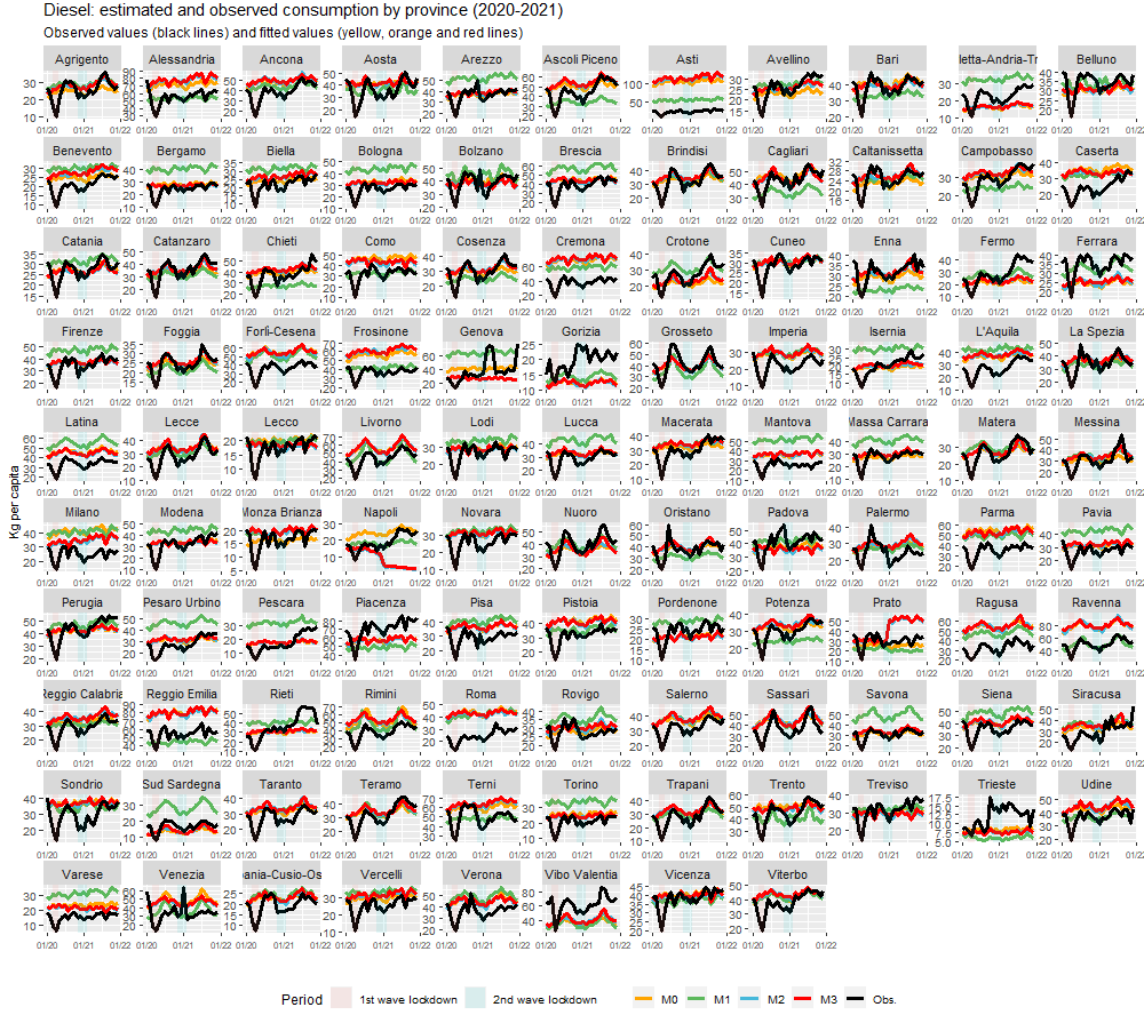


Figure S16: Time series of observed (black solid lines) and estimated (red, orange and yellow solid lines) per capita diesel consumption in 2020 and 2021 by province. Yellow, orange and red lines correspond to model M0, M1 and M2, respectively.

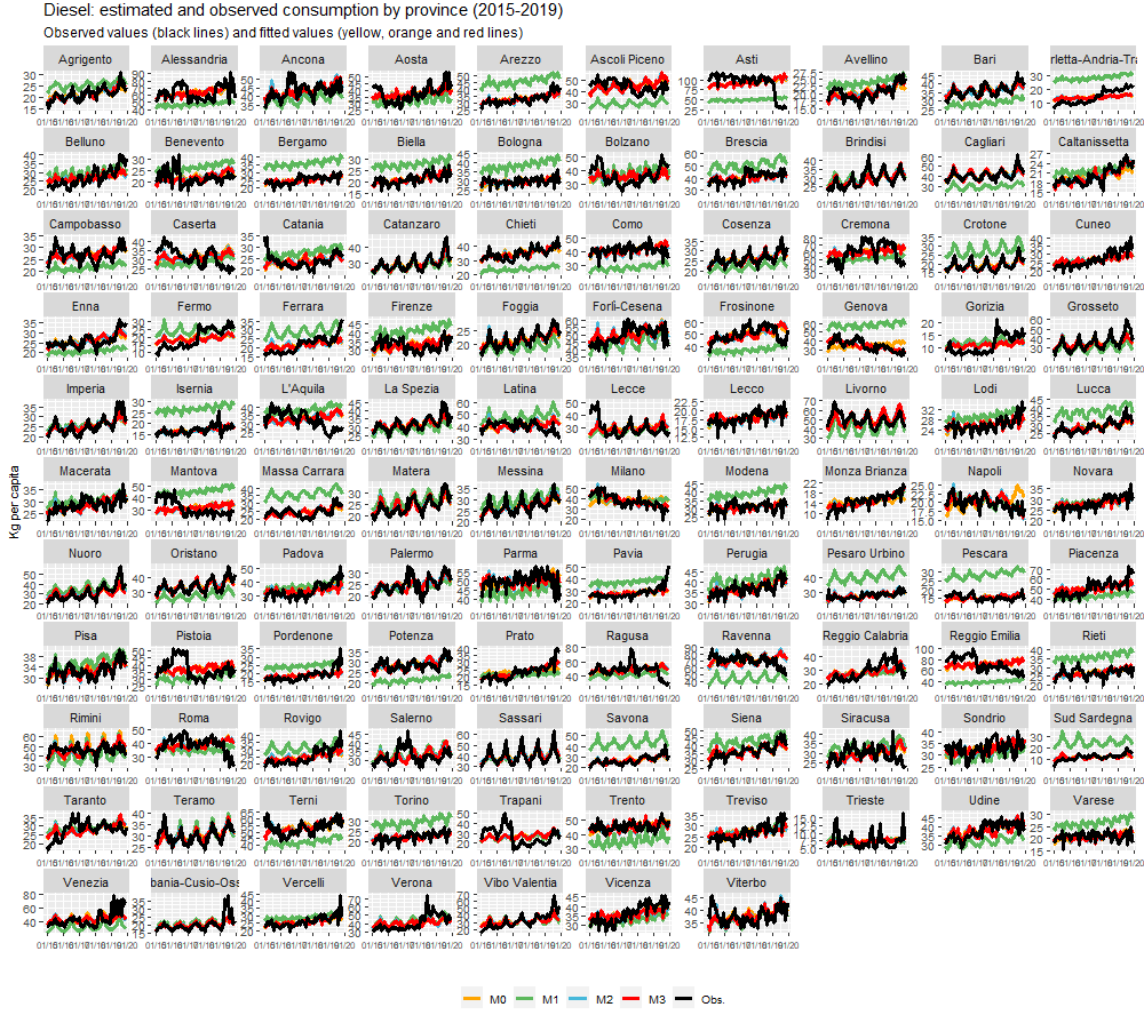


Figure S17: Time series of observed (black solid lines) and estimated (red, orange and yellow solid lines) per capita diesel consumption during the training period (2015-2019) by province. Yellow, orange and red lines correspond to model M0, M1 and M2, respectively.

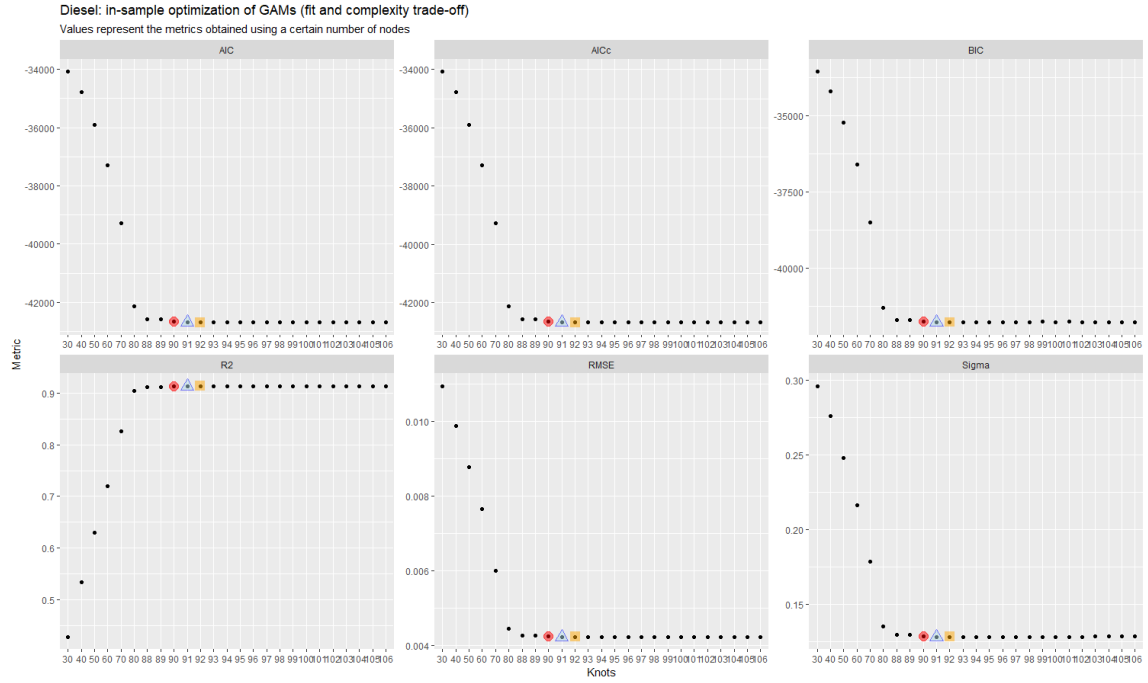


Figure S18: Diesel (M2): in-sample accuracy metrics computed for growing number of nodes k of the Duchon bivariate spline (spatial smooth). Values are computed aggregating prediction errors from 2015 to 2018.

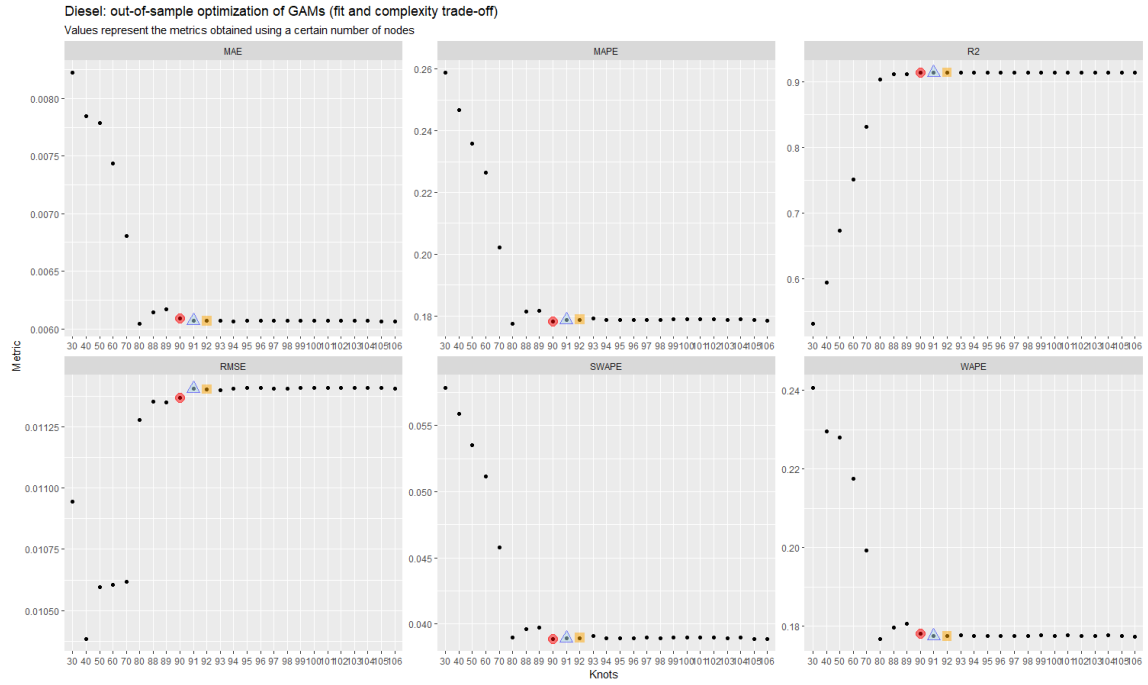


Figure S19: Diesel (M2): out-of-sample accuracy metrics computed for growing number of nodes k of the Duchon bivariate spline (spatial smooth). Values are computed aggregating prediction errors just for 2019.

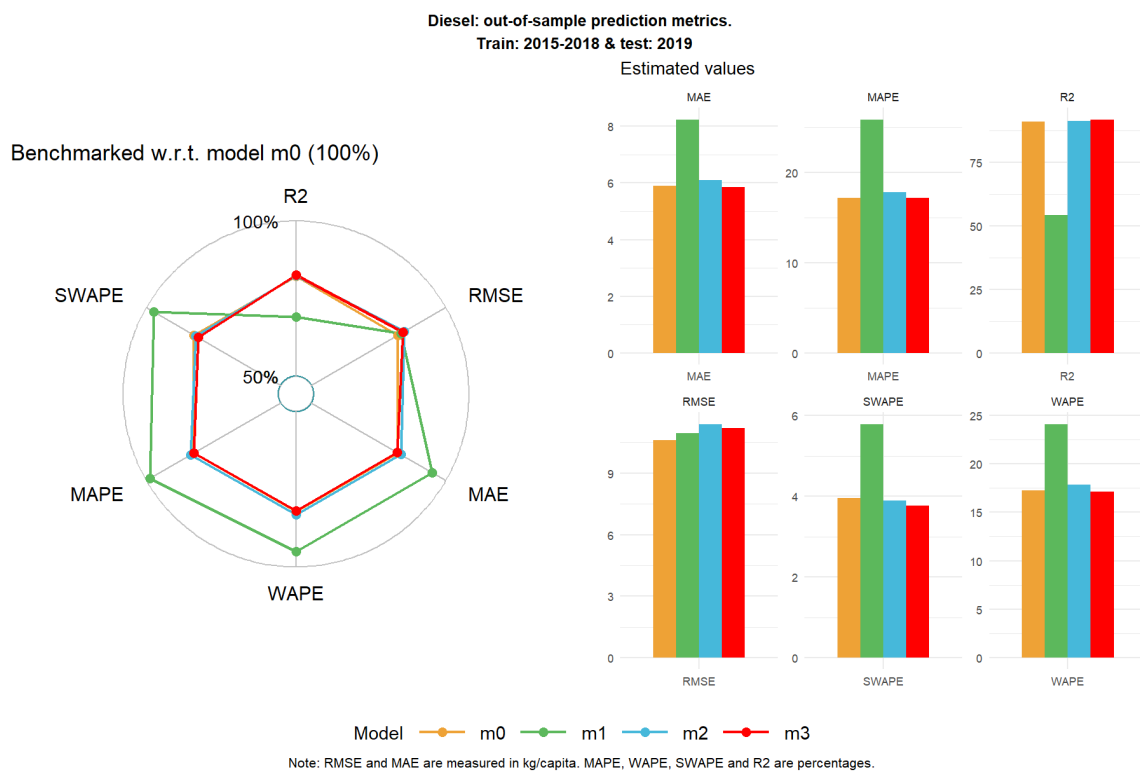


Figure S20: Diesel: out-of-sample prediction metrics computed using 2019 as test set and 2015-2018 as training set.

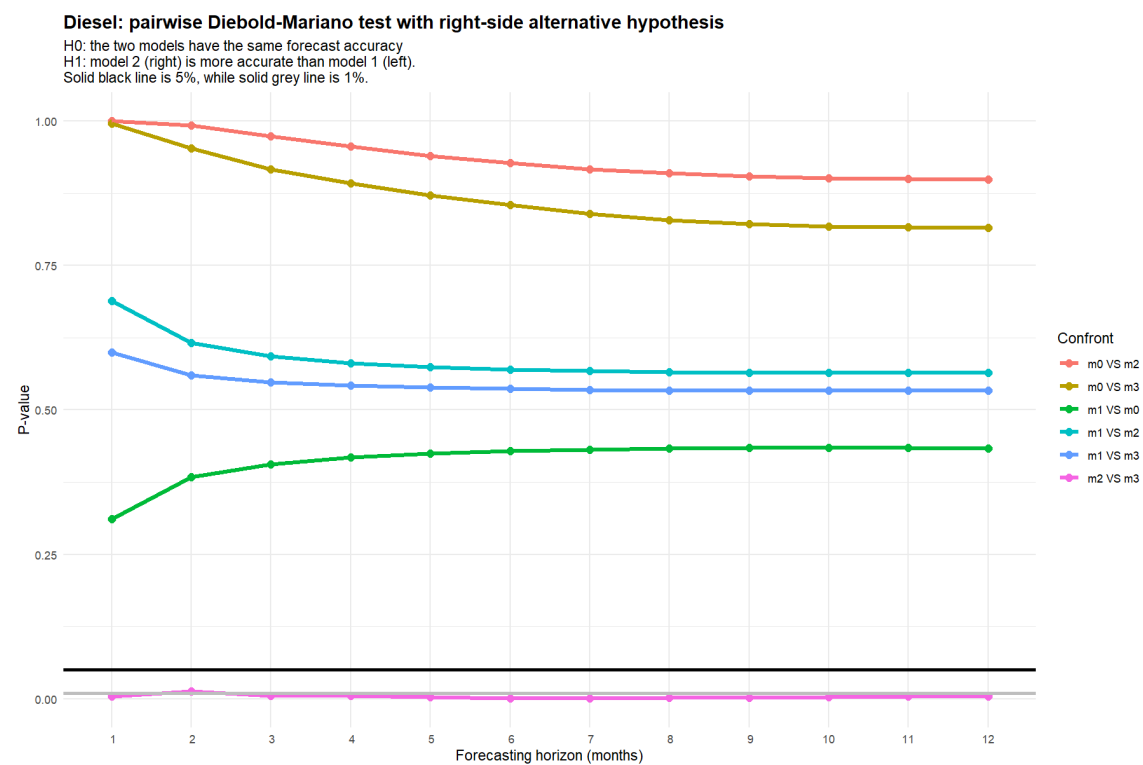


Figure S21: Diesel: pairwise Diebold-Mariano test with right-side alternative hypothesis computed using 2019 as test set and 2015-2018 as training set.

	m0: GLM	m1: GAMm2: optimal	GAMm3: opt.	GAM with ST inter.
(Intercept)	-70.09*** (2.82)	-3.50*** (0.04)	-14.64 (20.19)	-19.07 (18.66)
Month = February	-0.00 (0.01)			
Month = March	0.12*** (0.01)			
Month = April	0.10*** (0.01)			
Month = May	0.16*** (0.02)			
Month = June	0.13*** (0.02)			
Month = July	0.13*** (0.02)			
Month = August	0.05* (0.02)			
Month = September	0.12*** (0.02)			
Month = October	0.18*** (0.02)			
Month = November	0.09*** (0.01)			
Month = December	0.11*** (0.01)			
Year	0.03*** (0.00)			
Tourists_stays_pc	0.03*** (0.00)			
HDD	0.00** (0.00)			
CDD	0.00*** (0.00)			
Density	-0.00* (0.00)			
Surface	0.00 (0.00)			
UrbDegree = predominantly urban	0.94*** (0.17)	-0.20*** (0.02)	-11.34*** (1.29)	-11.68*** (1.22)
UrbDegree = predominantly rural	0.43*** (0.04)	0.15*** (0.02)	-5.43** (2.00)	-4.62** (1.69)
Border = Other regions	0.73*** (0.20)	-0.08** (0.03)	4.60*** (0.82)	3.90*** (0.35)
Coastal = on coast	-0.64*** (0.17)	0.04 (0.02)	8.11 (20.49)	13.07 (18.77)
Coastal = non-coastal	0.20*** (0.04)	0.22*** (0.03)	25.69 (21.53)	31.68 (19.33)
Non metropolitan	-0.05 (0.03)	0.03* (0.02)	-3.88*** (0.41)	-4.01*** (0.37)
s(Month)		9.73*** (10.00)	9.96*** (10.00)	10.00*** (10.00)
s(Year)		2.48*** (2.98)	3.73*** (3.96)	3.41*** (3.80)
s(Tourists_stays_pc)		6.65*** (7.42)	6.93*** (7.63)	3.42*** (4.19)
s(CDD)		1.88** (2.35)	4.20*** (5.10)	4.56* (5.49)
s(HDD)		1.00 (1.00)	1.58 (1.98)	1.00*** (1.00)
s(Density)		9.00*** (9.00)	8.74*** (8.94)	8.74*** (8.94)
s(Surface)		9.00*** (9.00)	9.00*** (9.00)	7.83*** (7.96)
s(long,lat)		29.68*** (30.00)	89.75*** (91.00)	90.91*** (91.00)
ti(long,lat,Month)				63.36*** (190.00)
AIC	-51120.93	-42591.83	-51477.43	-51720.23
BIC	-50281.80	-42067.92	-50517.14	-50358.40
Log Likelihood	25684.46	21373.33	25880.62	26061.36
Deviance	141.38	534.51	133.00	125.71
Num. smooth terms		8	8	9

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$

Table S2: Diesel: estimated models using training data from January 2015 to December 2019

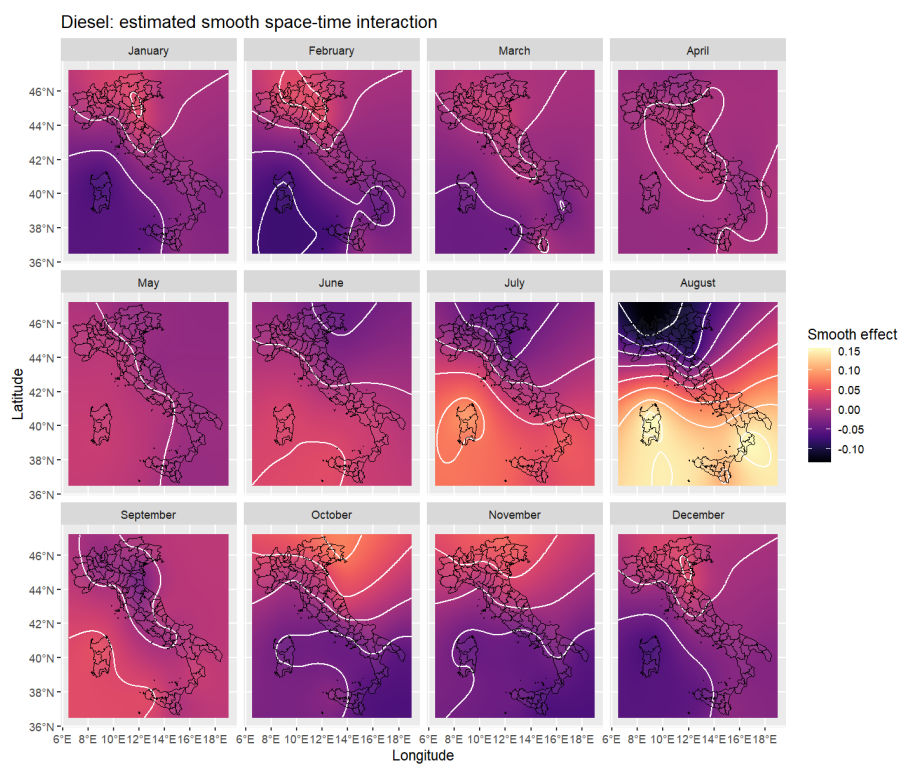


Figure S22: Diesel: estimated monthly smooth spatial surface (M3).

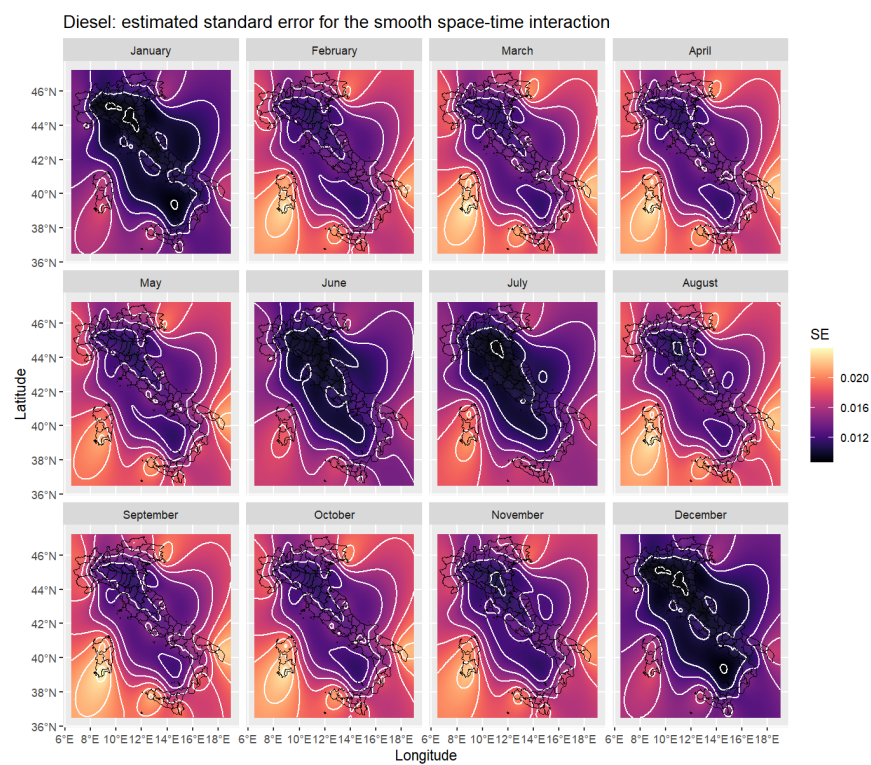


Figure S23: Diesel: estimated standard error for the smooth space-time interaction (M3).

Diesel: (dis)similarity measures for out-of-sample residuals by macro-regions

	Corr. in 2020 and 2021					Corr. in 2020					Corr. in 2021					Var. corr. from 2020 to 2021				
South	0.96	0.94	0.91	0.92	1	0.99	0.99	0.97	0.99	1	0.98	0.89	0.89	0.84	1	0	-0.1	-0.08	-0.15	0
North-West	0.97	0.97	0.97	1	0.92	0.99	0.99	0.98	1	0.99	0.84	0.86	0.87	1	0.84	-0.15	-0.13	-0.1	0	-0.15
North-East	0.98	0.95	1	0.97	0.91	0.99	0.98	1	0.98	0.97	0.9	0.78	1	0.87	0.89	-0.09	-0.2	0	-0.1	-0.08
Islands	0.98	1	0.95	0.97	0.94	0.99	1	0.98	0.99	0.99	0.88	1	0.78	0.86	0.89	-0.11	0	-0.2	-0.13	-0.1
Center	1	0.98	0.98	0.97	0.96	1	0.99	0.99	0.99	0.99	1	0.88	0.9	0.84	0.98	0	-0.11	-0.09	-0.15	0
	Cos. dist. in 2020 and 2021					Cos. dist. in 2020					Cos. dist. in 2021					Var. cos. dist. from 2020 to 2021				
South	0.82	0.87	0.85	0.66	1	0.97	0.99	0.98	0.92	1	0.21	0.37	0.25	-0.09	1	-0.76	-0.62	-0.73	-1.01	0
North-West	0.96	0.91	0.92	1	0.66	0.98	0.95	0.94	1	0.92	0.94	0.85	0.92	1	-0.09	-0.04	-0.1	-0.02	0	-1.01
North-East	0.98	0.97	1	0.92	0.85	0.98	0.99	1	0.94	0.98	0.97	0.9	1	0.92	0.25	-0.02	-0.09	0	-0.02	-0.73
Islands	0.97	1	0.97	0.91	0.87	0.99	1	0.99	0.95	0.99	0.93	1	0.9	0.85	0.37	-0.05	0	-0.09	-0.1	-0.62
Center	1	0.97	0.98	0.96	0.82	1	0.99	0.98	0.98	0.97	1	0.93	0.97	0.94	0.21	0	-0.05	-0.02	-0.04	-0.76
	Eucl. dist. in 2020 and 2021					Eucl. dist. in 2020					Eucl. dist. in 2021					Var. Eucl. dist. from 2020 to 2021				
South	26.68	13.56	19.4	41.53	0	16.87	4.41	10.93	24.68	0	20.66	12.82	16.04	33.4	0	3.79	8.41	5.11	8.73	0
North-West	16.61	30.34	25	0	41.53	9.69	21.46	17.31	0	24.68	13.5	21.45	18.04	0	33.4	3.81	-0.01	0.73	0	8.73
North-East	10.83	10.29	0	25	19.4	8.43	7.91	0	17.31	10.93	6.79	6.59	0	18.04	16.04	-1.65	-1.32	0	0.73	5.11
Islands	16.81	0	10.29	30.34	13.56	13.58	0	7.91	21.46	4.41	9.9	0	6.59	21.45	12.82	-3.68	0	-1.32	-0.01	8.41
Center	0	16.81	10.83	16.61	26.68	0	13.58	8.43	9.69	16.87	0	9.9	6.79	13.5	20.66	0	-3.68	-1.65	3.81	3.79
Center	Islands	North-East	North-West	South		Center	Islands	North-East	North-West	South	Center	Islands	North-East	North-West	South	Center	Islands	North-East	North-West	South

Figure S24: Diesel: (dis)similarity measures for out-of-sample residuals by macro-regions.

Section S3. Other results

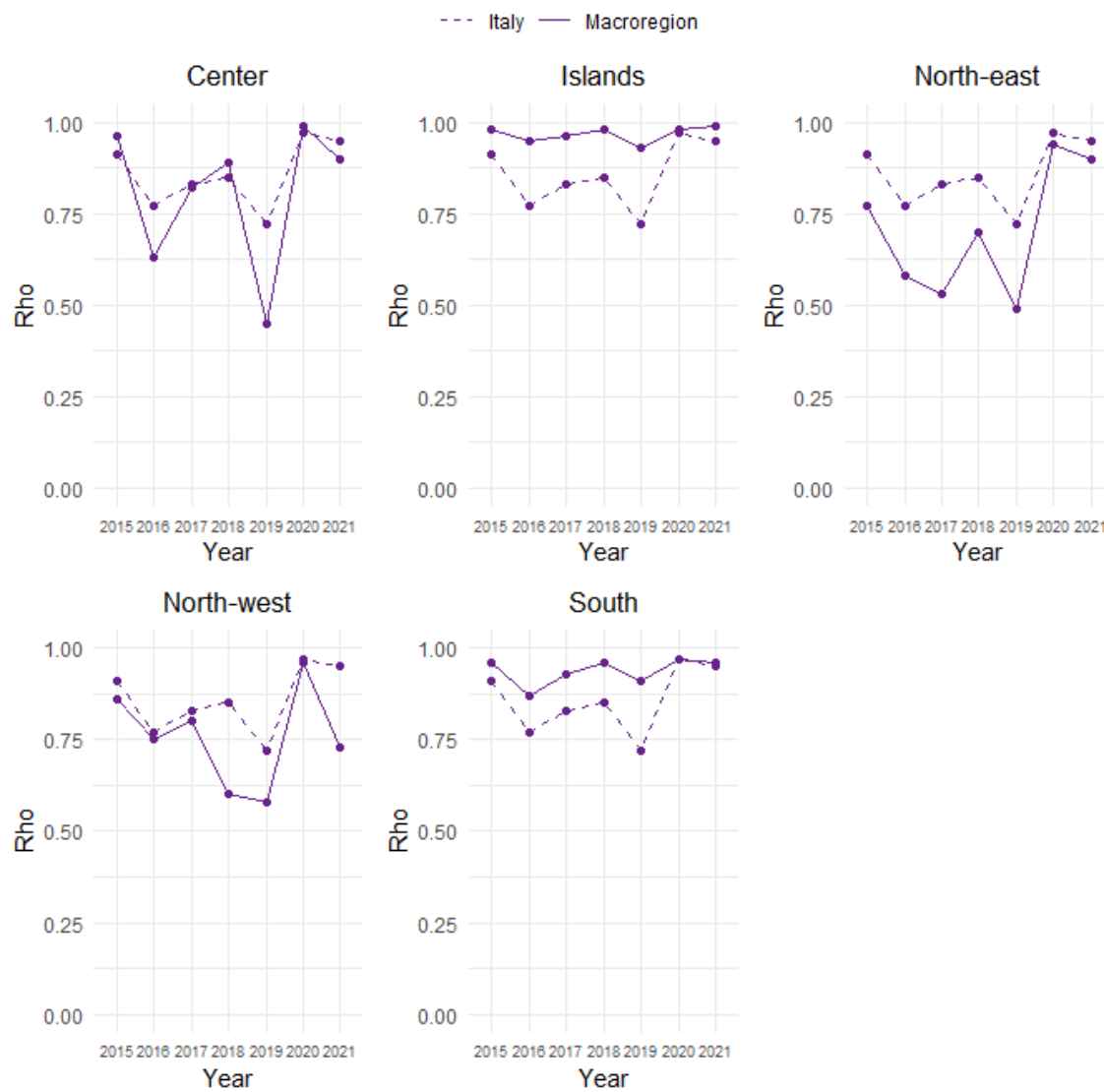


Figure S25: Correlation between annual consumption of gasoline, diesel and LPG grouped by Eurostat NUTS-1 macro-regions.

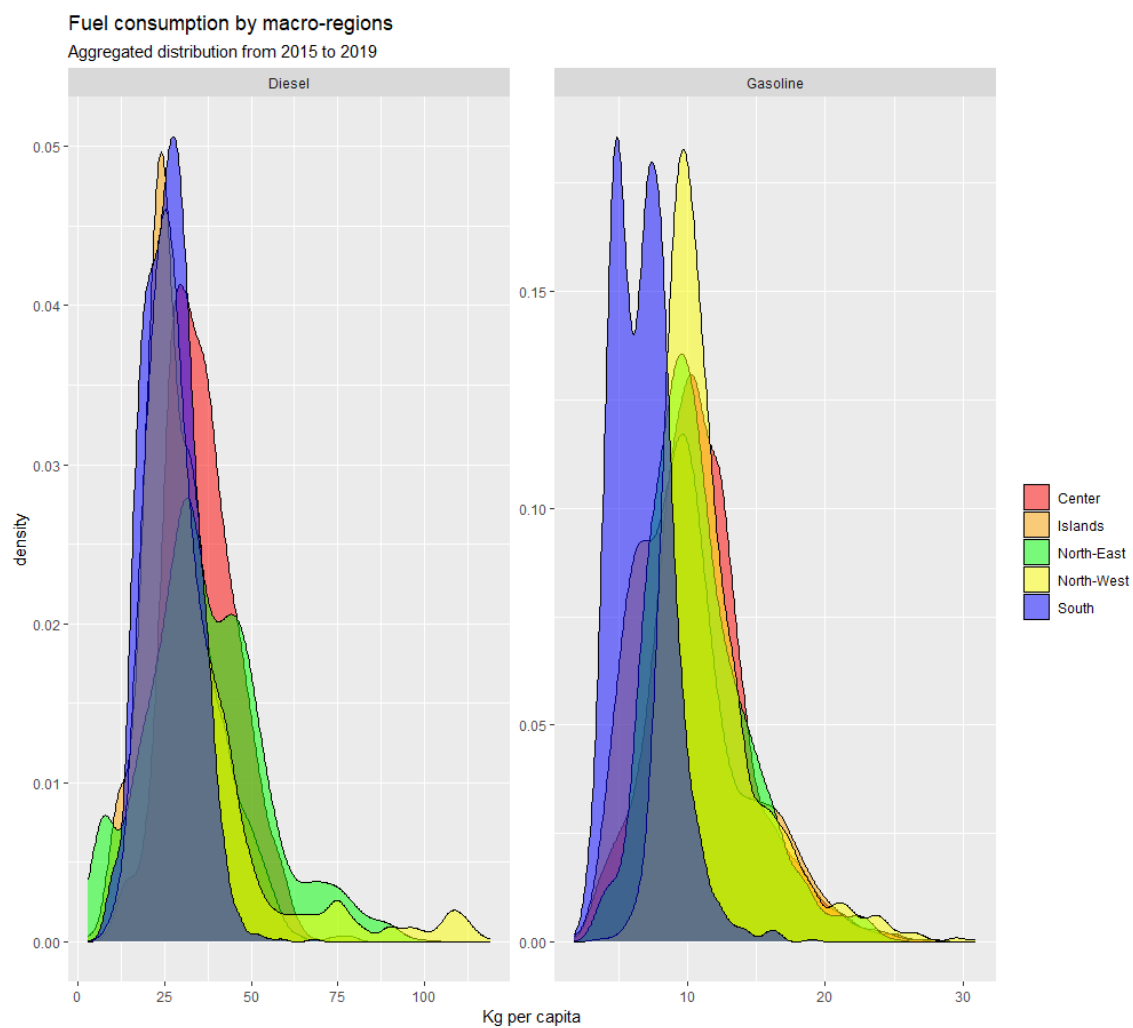


Figure S26: Aggregate empirical distribution (all provinces and all months combined) of gasoline (left panel) and diesel (right panel) registered during the pre-COVID period (from January 2015 to December 2019) grouped by Eurostat NUTS-1 macro-regions.