

Supplementary Information

The estimation results for the full sample period and various sub-samples are presented below and briefly discussed. Estimated coefficients and corresponding p -values are reported to assess the statistical significance of the explanatory variables. Significance levels are denoted as follows: 0.1% (****), 1% (***), 5% (**), 10% (*).

Hive locations for years 2020-2023

Figure B4, Figure B5, Figure B6 and Figure B7 display the geographical distribution of hives across altitudinal zones in Italy in 2023, 2022, 2021 and 2020 respectively.

Quantile regression for years 2020-2023

Quantile regression estimates for the period 2020–2023 are reported in Table B3 (linear coefficients) and Table B4 (interaction coefficients). Regarding the main results for the most recent year (2024), linear coefficients were generally statistically significant and negative, whereas interaction coefficients, when significant, were positive, consistent with the documented antagonistic effect. The only notable exception is the reversal of the estimated coefficients of temperature volatility and air pollution in 2023.

VIFs for years 2020-2023

Table B5 reports the variance inflation factors (VIFs) estimated for years 2020-2023. It is evident that the inclusion of interaction terms introduces multicollinearity throughout the sample, necessitating the use of standardized versions of the variables in the regression analysis.

If a regressor is highly correlated with other regressors, the regression has difficulty separating their individual coefficient contributions. As a result: the variance of the coefficient estimate increases; standard errors become larger; coefficients can become unstable or change sign. If $VIF = v$, the variance of the coefficient estimate is v times larger than it would be if the regressor were uncorrelated with the others.

Quantile regression for years 2020-2024 on standardized variables

Table B6 (linear coefficients) and Table B7 (interaction coefficients) report the estimated quantile regressions for all years, including 2024, using standardized variables. Standardization is performed at the cluster level. All stressors and their interactions are highly statistically significant. As expected, the pseudo- R^2 values are substantially higher than those obtained from regressions based on unstandardized data.

AMEs of migratory vs non-migratory for years 2020-2023

Table B8 reports the estimated average marginal effects (AMEs) for migratory versus non-migratory beekeeping over the period 2020–2023. As for the year 2024, the estimates for migratory hives are consistent with weaker negative associations with environmental stressors, particularly those reflected in hive-weight volatility.

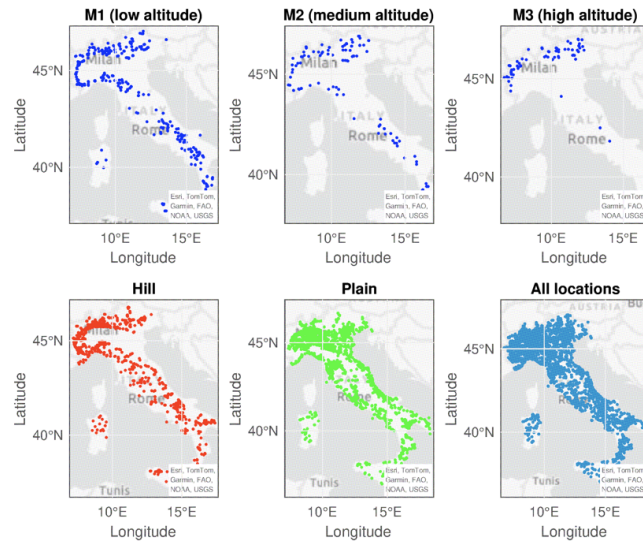


Fig. B4: Distribution of hives across altitudinal zones in Italy in 2023

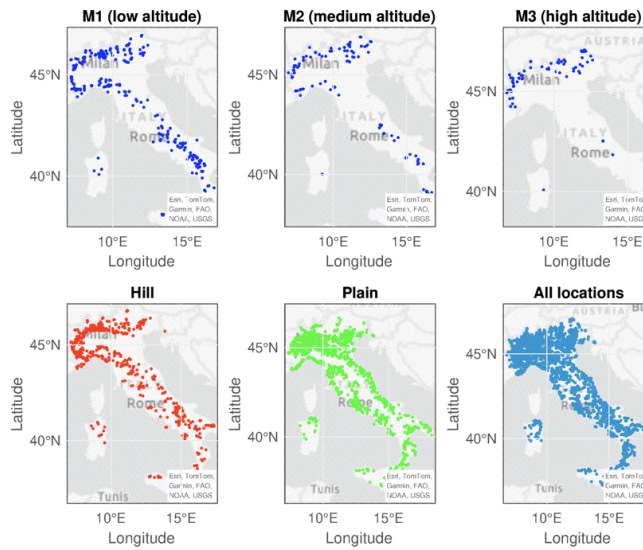


Fig. B5: Distribution of hives across altitudinal zones in Italy in 2022

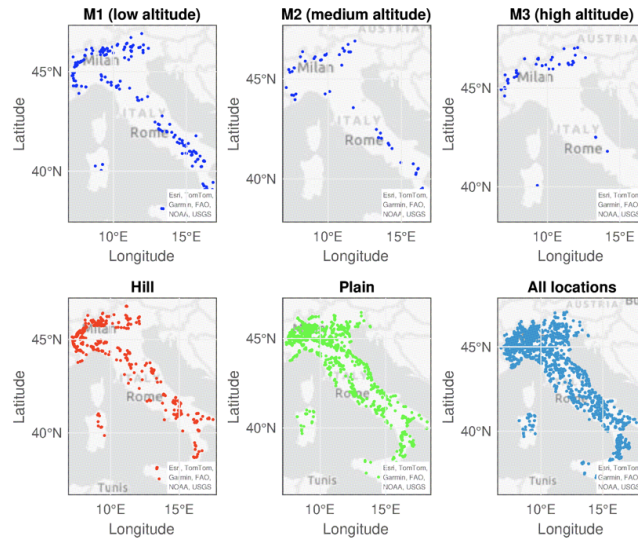


Fig. B6: Distribution of hives across altitudinal zones in Italy in 2021

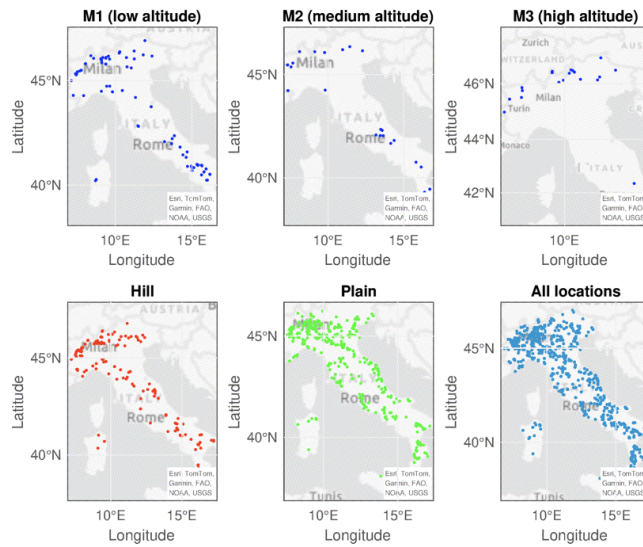


Fig. B7: Distribution of hives across altitudinal zones in Italy in 2020

Year	Quantile	Weight	Vol	Temp	Vol	Air	Pollution	pseudo- R^2
2023	$q_{0.1}$	-0.0129 0.0010	***	0.0186 0.0000	****	0.0226 0.0050	***	0.0180
	$q_{0.25}$	-0.0079 0.0000	****	0.0139 0.0000	****	0.0204 0.0000	****	0.0065
	$q_{0.5}$	0.0004 0.8640		0.0142 0.0000	****	0.0285 0.0000	****	0.0099
	$q_{0.75}$	0.0119 0.0010	***	0.0221 0.0040	***	0.0533 0.0010	***	0.0340
	$q_{0.9}$	0.0196 0.0060	***	0.0253 0.3220		0.0682 0.2700		0.0353
N. obs		48,710						
N. hives		2,578						
N. clusters		209						
2022	$q_{0.1}$	-0.0123 0.0000	****	-0.0041 0.4050		-0.0074 0.3920		0.0151
	$q_{0.25}$	-0.0101 0.0000	****	-0.0107 0.0000	****	-0.0168 0.0000	****	0.0119
	$q_{0.5}$	-0.0109 0.0000	****	-0.0061 0.0460	**	-0.0043 0.4570		0.0302
	$q_{0.75}$	-0.0157 0.0000	****	-0.0043 0.4160		0.0067 0.5660		0.0711
	$q_{0.9}$	-0.0135 0.0650	*	-0.0087 0.5220		0.0112 0.7170		0.0840
N. obs		37,490						
N. hives		2,133						
N. clusters		155						
2021	$q_{0.1}$	-0.0080 0.1870		0.0142 0.1830		0.0220 0.1950		0.0338
	$q_{0.25}$	-0.0054 0.1220		0.0052 0.2250		0.0095 0.2100		0.0135
	$q_{0.5}$	0.0002 0.9580		-0.0085 0.1450		-0.0074 0.4570		0.0118
	$q_{0.75}$	0.0002 0.9640		-0.0323 0.0100	**	-0.0399 0.0600	*	0.0530
	$q_{0.9}$	0.0048 0.4260		-0.0504 0.0160	**	-0.0661 0.0810	*	0.0727
N. obs		20,913						
N. hives		1,331						
N. clusters		104						
2020	$q_{0.1}$	0.0049 0.4660		0.0333 0.0000	****	0.0634 0.0010	***	0.0040
	$q_{0.25}$	0.0024 0.5650		0.0147 0.0010	***	0.0354 0.0000	****	0.0011
	$q_{0.5}$	0.0098 0.0640	*	0.0159 0.0010	***	0.0421 0.0000	****	0.0017
	$q_{0.75}$	0.0256 0.0060	***	0.0279 0.0020	***	0.0827 0.0000	****	0.0055
	$q_{0.9}$	0.0452 0.0230	**	0.0353 0.0580	*	0.1309 0.0010	***	0.0062
N. obs		7,575						
N. hives		574						
N. clusters		93						

Table B3: Estimated coefficients (top) and p -values (bottom) of linear coefficients across quantiles for the years 2020-2023.

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			Weight Vol × Air pollution	Temp Vol × Air pollution	Weight Vol × Temp Vol	pseudo- R^2
2023	$q_{0.1}$	0.0024 0.0230	**	-0.0055 0.0000	**** 0.0007 0.0970	* 0.0180
	$q_{0.25}$	0.0015 0.0010	***	-0.0041 0.0000	**** 0.0007 0.0000	**** 0.0065
	$q_{0.5}$	0.0005 0.3490		-0.0048 0.0000	**** 0.0003 0.9300	 0.0099
	$q_{0.75}$	-0.0019 0.0250	**	-0.0085 0.0050	*** 0.0002 0.6470	 0.0340
	$q_{0.9}$	-0.0106 0.3030		-0.0029 0.1340	0.00002 0.9790	 0.0353
	N. obs	48,710				
	N. hives	2,578				
	N. clusters	209				
2022	$q_{0.1}$	0.0032 0.0000	****	0.0021 0.2720	0.0002 0.5540	 0.0151
	$q_{0.25}$	0.0032 0.0000	****	0.0044 0.0000	0.0003 0.2760	 0.0119
	$q_{0.5}$	0.0042 0.0000	****	0.0021 0.0770	* 0.1050	 0.0302
	$q_{0.75}$	0.0055 0.0000	****	0.0008 0.7240	0.0016 0.0050	*** 0.0711
	$q_{0.9}$	0.0065 0.0000	****	0.0026 0.6490	0.0012 0.1780	 0.0840
	N. obs	37,490				
	N. hives	2,133				
	N. clusters	155				
2021	$q_{0.1}$	-0.0038 0.3370		0.0008 0.6430	0.0002 0.6810	 0.0338
	$q_{0.25}$	0.0011 0.2920		-0.0008 0.6130	0.0001 0.7570	 0.0135
	$q_{0.5}$	0.0010 0.4920		0.0033 0.0900	* 0.5750	 0.0118
	$q_{0.75}$	0.0014 0.2860		0.0112 0.0130	** 0.2290	 0.0530
	$q_{0.9}$	0.0029 0.0460	**	0.0170 0.0180	** 0.4700	 0.0727
	N. obs	20,913				
	N. hives	1,331				
	N. clusters	104				
2020	$q_{0.1}$	-0.0016 0.3060		-0.0114 0.0020	*** -0.0014 0.0910	* 0.0040
	$q_{0.25}$	0.0007 0.4590		-0.0059 0.0010	*** -0.0012 0.0190	 0.0011
	$q_{0.5}$	0.0011 0.3630		-0.0072 0.0000	**** -0.0020 0.0170	 0.0017
	$q_{0.75}$	0.0016 0.4800		-0.0140 0.0000	**** -0.0041 0.0010	 0.0055
	$q_{0.9}$	0.0006 0.8980		-0.0198 0.0100	** -0.0064 0.0070	 0.0062
	N. obs	7,575				
	N. hives	574				
	N. clusters	93				

Table B4: Estimated coefficients (top) and p -values (bottom) of interaction coefficients across quantiles for the years 2020-2023.

Year	VIF	Weight Vol	Temp Vol	Air Pollution	Weight Vol × Temp Vol	Weight Vol × Air Pollution	Temp Vol × Air Pollution
2023	Unstandardized	122.37	47.52	48.83	50.07	49.05	71.21
	Standardized	1.06	1.06	1.12	1.13	1.13	1.07
2022	Unstandardized	95.74	52.74	41.67	48.38	56.61	98.07
	Standardized	1.07	1.06	1.03	1.01	1.11	1.08
2021	Unstandardized	135.65	56.79	80.28	78.51	42.32	113.32
	Standardized	1.06	1.08	1.07	1.12	1.08	1.10
2020	Unstandardized	95.36	33.88	53.99	62.52	33.78	79.1
	Standardized	1.06	1.06	1.09	1.08	1.09	1.10

Table B5: VIFs of unstandardized versus standardized explanatory variables over the years 2020-2023.

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Year	Quantile	Weight	Vol	Temp	Vol	Air	Pollution	pseudo R^2
2024	q0.1	-0.1431 0.0000	****	0.0760 0.0000	****	0.0392 0.0000	****	0.0425
	q0.25	0.0089 0.4040		0.0665 0.0000	****	0.0582 0.0000	****	0.0145
	q0.5	0.1966 0.0000	****	0.0599 0.0000	****	0.0855 0.0000	****	0.0528
	q0.75	0.4505 0.0000	****	0.0531 0.0000	****	0.0807 0.0000	****	0.1633
	q0.9	0.6740 0.0000	****	0.0396 0.0480	**	0.0815 0.0000	****	0.2729
	N. obs 46687 N. hives 2288 N. clusters 154							
2023	q0.1	-0.1395 0.0000	****	0.0575 0.0000	****	0.0118 0.1710		0.0534
	q0.25	0.0065 0.3860		0.0496 0.0000	****	0.0289 0.0000	****	0.0143
	q0.5	0.1799 0.0000	****	0.0265 0.0060	***	0.0446 0.0000	****	0.0530
	q0.75	0.4404 0.0000	****	0.0040 0.7890		0.0600 0.0010	***	0.1711
	q0.9	0.6601 0.0000	****	-0.0425 0.0090	***	0.0510 0.0040	***	0.2790
	N. obs 48710 N. hives 2578 N. clusters 209							
2022	q0.1	0.0492 0.0000	****	0.0211 0.0000	****	-0.0253 0.1460		0.0390
	q0.25	0.0244 0.0290	**	0.0010 0.9120		0.0640 0.0000	****	0.0299
	q0.5	0.1723 0.0000	****	-0.0013 0.8920		0.0792 0.0000	****	0.0973
	q0.75	0.4000 0.0000	****	-0.0192 0.2210		0.1577 0.0000	****	0.2423
	q0.9	0.6073 0.0000	****	-0.0281 0.1130		0.1764 0.0000	****	0.3646
	N. obs 37490 N. hives 2133 N. clusters 155							
2021	q0.1	-0.1675 0.0000	****	0.0273 0.0990	*	0.0592 0.0000	****	0.0606
	q0.25	-0.0215 0.1170		0.0154 0.2090		0.0632 0.0000	****	0.0194
	q0.5	0.1460 0.0000	****	0.0057 0.6780		0.0851 0.0000	****	0.0489
	q0.75	0.3936 0.0000	****	-0.0123 0.4410		0.1029 0.0000	****	0.1577
	q0.9	0.5966 0.0000	****	-0.0517 0.0020	***	0.1055 0.0000	****	0.2675
	N. obs 20913 N. hives 1331 N. clusters 104							
2020	q0.1	-0.1544 0.0000	****	0.0023 0.8970		0.0515 0.0280	**	0.0385
	q0.25	-0.0060 0.6630		-0.0026 0.7720		0.0510 0.0000	***	0.0104
	q0.5	0.1277 0.0000	****	-0.0437 0.0010	***	0.0609 0.0000	****	0.0483
	q0.75	0.3740 0.0000	****	-0.1067 0.0000	****	0.1377 0.0000	****	0.1675
	q0.9	0.6148 0.0000	****	-0.1338 0.0000	****	0.1976 0.0000	****	0.2903
	N. obs 7575 N. hives 574 N. clusters 93							

Table B6: Estimated coefficients (top) and p -values (bottom) of linear coefficients (standardized) across quantiles for all the years in the sample of analysis.

Year	Quantile	Weight Vol × Air pollution		Temp Vol × Air pollution		Weight Vol × Temp Vol		pseudo R^2
2024	$q_{0.1}$	0.0355 0.0000	****	0.0303 0.0000	****	0.0240 0.0030	***	0.0425
	$q_{0.25}$	0.0455 0.0000	****	0.0419 0.0000	****	0.0416 0.0000	****	0.0145
	$q_{0.5}$	0.0599 0.0000	****	0.0500 0.0000	****	0.0729 0.0000	****	0.0528
	$q_{0.75}$	0.0355 0.0000	****	0.0635 0.0000	****	0.0993 0.0000	****	0.1633
	$q_{0.9}$	0.0082 0.3830		0.0722 0.0000	****	0.0963 0.0000	****	0.2729
	N. obs	46687						
	N. hives	2288						
	N. clusters	154						
2023	$q_{0.1}$	0.0191 0.0010	***	-0.0100 0.0170	**	0.0269 0.0000	****	0.0534
	$q_{0.25}$	0.0262 0.0000	****	-0.0158 0.0000	****	0.0343 0.0000	****	0.0143
	$q_{0.5}$	0.0177 0.0120	**	-0.0129 0.0240	**	0.0303 0.0000	****	0.0530
	$q_{0.75}$	-0.0028 0.8330		-0.0266 0.0070	***	0.0258 0.0240	**	0.1711
	$q_{0.9}$	-0.0269 0.0430	**	-0.0203 0.1180		0.0083 0.4140		0.2790
	N. obs	48710						
	N. hives	2578						
	N. clusters	209						
2022	$q_{0.1}$	-0.1129 0.0000	****	0.0044 0.7890		0.0590 0.0000	****	0.0390
	$q_{0.25}$	0.0492 0.0000	****	0.0122 0.0000	****	-0.0109 0.2530		0.0299
	$q_{0.5}$	0.0610 0.0000	****	0.0050 0.1830		0.0077 0.4320		0.0973
	$q_{0.75}$	0.1126 0.0000	****	-0.0166 0.0130	**	0.0217 0.0640	*	0.2423
	$q_{0.9}$	0.1049 0.0000	****	-0.0267 0.0270	**	0.0232 0.0620	*	0.3646
	N. obs	37490						
	N. hives	2133						
	N. clusters	155						
2021	$q_{0.1}$	0.0345 0.0000	****	-0.0125 0.2010		-0.0104 0.3530		0.0606
	$q_{0.25}$	0.0377 0.0000	****	-0.0011 0.8620		0.0029 0.7880		0.0194
	$q_{0.5}$	0.0521 0.0010	***	0.0221 0.0040	***	0.0216 0.0320	**	0.0489
	$q_{0.75}$	0.0422 0.0380	**	0.0488 0.0000	****	0.0315 0.0150	**	0.1577
	$q_{0.9}$	0.0174 0.2800		0.0693 0.0000	****	0.0251 0.0070	***	0.2675
	N. obs	20913						
	N. hives	1331						
	N. clusters	104						
2020	$q_{0.1}$	0.0334 0.0070	***	-0.0273 0.0120	**	-0.0155 0.2770		0.0385
	$q_{0.25}$	0.0265 0.0120	**	-0.0178 0.0500	*	-0.0111 0.2870		0.0104
	$q_{0.5}$	0.0261 0.0310	**	-0.0376 0.0000	****	-0.0419 0.0070	***	0.0483
	$q_{0.75}$	0.0501 0.0210	**	-0.0622 0.0000	****	-0.0634 0.0150	**	0.1675
	$q_{0.9}$	0.0399 0.1220		-0.0721 0.0060	***	-0.0492 0.1450		0.2903
	N. obs	7575						
	N. hives	574						
	N. clusters	93						

Table B7: Estimated coefficients (top) and p -values (bottom) of interaction coefficients (standardized) across quantiles for all the years in the sample of analysis.

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		Non-migratory			Migratory		
		AME	p-value		AME	p-value	
2023							
	Weight Vol	-0.018	0.078	*	Weight Vol	-0.029	0.429
	Temp Vol	0.013	0.215		Temp Vol	0.041	0.880
	Air Pollution	0.039	0.029	**	Air Pollution	0.153	0.778
	N. obs	14,046			N. obs	15,946	
2022							
	Weight Vol	-0.019	0.043	**	Weight Vol	-0.099	0.141
	Temp Vol	0.003	0.822		Temp Vol	-0.185	0.211
	Air Pollution	0.021	0.324		Air Pollution	-0.306	0.245
	N. obs	9,110			N. obs	13,599	
2021							
	Weight Vol	-0.024	0.010	**	Weight Vol	-0.236	0.214
	Temp Vol	-0.014	0.359		Temp Vol	-0.225	0.559
	Air Pollution	-0.010	0.705		Air Pollution	-0.351	0.530
	N. obs	4,067			N. obs	7,188	
2020							
	Weight Vol	0.080	0.002	***	Weight Vol	-0.002	0.951
	Temp Vol	0.139	0.031	**	Temp Vol	0.194	0.009
	Air Pollution	0.279	0.020	**	Air Pollution	0.462	0.005
	N. obs	991			N. obs	2,635	

Table B8: Average marginal effects (AMEs) of stressors over non-migratory versus migratory hives for the years 2020-2023.