Aggregated *versus* individual land-use models: Modeling spatial autocorrelation to increase predictive accuracy

Supporting Information

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1 Estimation results from individual MNL models

Table 1: Individual MNL models on 1993–2003

| | | Long Run | | | Short Run | |
	arable use	forest use	urban use	arable use	forest use	urban use
U93PSTUR				−1.861***	−3.032***	−3.590***
				(0.008)	(0.013)	(0.017)
U93ARBLE				1.592***	−3.120***	−2.548***
				(0.009)	(0.035)	(0.025)
U93FORST				−1.477***	3.939***	−1.217***
				(0.043)	(0.019)	(0.041)
U93URBAN				−1.245***	−1.315***	2.865***
				(0.054)	(0.059)	(0.028)
Arable returns03	0.495***	0.332***	0.391***	0.288***	0.170***	0.252***
	(0.005)	(0.005)	(0.008)	(0.007)	(0.012)	(0.013)
Pasture returns03	−0.269***	−0.308***	−0.257***	−0.143***	−0.237***	−0.199***
	(0.005)	(0.005)	(0.007)	(0.006)	(0.012)	(0.013)
Forest returns03	0.006	0.335***	0.070***	0.034***	0.181***	−0.049***
	(0.005)	(0.004)	(0.007)	(0.006)	(0.010)	(0.013)
POP03	−0.615***	−0.122***	0.120***	−0.262***	−0.047***	0.046***
	(0.013)	(0.008)	(0.005)	(0.013)	(0.008)	(0.005)
Elevation	−0.903***	−0.224***	−0.533***	−0.616***	−0.153***	−0.275***
	(0.012)	(0.007)	(0.017)	(0.017)	(0.019)	(0.029)
Slope	−0.224***	0.148***	0.034***	−0.136***	0.141***	−0.005
	(0.009)	(0.005)	(0.011)	(0.012)	(0.012)	(0.019)
WHC	0.262***	−0.238***	0.091***	0.157***	−0.089***	0.009
	(0.008)	(0.008)	(0.012)	(0.010)	(0.020)	(0.022)
Soil depth	−0.162***	0.204***	0.019	−0.082***	0.077***	0.031
	(0.007)	(0.008)	(0.012)	(0.010)	(0.019)	(0.022)
Precipitations	−0.453***	0.078***	−0.122***	−0.324***	0.018*	−0.091***
	(0.005)	(0.004)	(0.008)	(0.008)	(0.010)	(0.014)
Temperature	0.088***	0.027***	−0.331***	0.022	−0.083***	−0.125***
	(0.011)	(0.008)	(0.016)	(0.015)	(0.020)	(0.028)
Humidity	−0.058***	−0.240***	−0.549***	−0.005	−0.394***	−0.407***
	(0.009)	(0.006)	(0.012)	(0.012)	(0.016)	(0.022)
Radiation	−0.066***	−0.208***	0.496***	−0.103***	0.172***	0.390***
	(0.011)	(0.009)	(0.016)	(0.015)	(0.022)	(0.029)
Constant	−0.286***	−0.060***	−1.629***			
	(0.005)	(0.004)	(0.007)			
Akaike Inf. Crit.	1,160,067.000	1,160,067.000	1,160,067.000	413,591.400	413,591.400	413,591.400

Note: *p<0.1; **p<0.05; ***p<0.01
on scaled explanatory variables. Reference= Pastures

2 Estimation results from the models estimated by OLS

Table 2: Linear logit-transformed OLS models of land use on 1993–2003

	Arable Share		Forest Share		Urban Share	
	long run	short run	long run	short run	long run	short run
ARlog93		0.900***				
		(0.020)				
FOlog93				0.937***		
				(0.017)		
URlog93						0.847***
						(0.021)
scale(Arable returns03)	0.510***	0.041**	0.272***	0.012	0.397***	0.060***
	(0.042)	(0.019)	(0.036)	(0.011)	(0.033)	(0.015)
scale(Pasture returns03)	−0.331***	−0.027	−0.325***	−0.030**	−0.234***	−0.045***
	(0.036)	(0.017)	(0.032)	(0.014)	(0.032)	(0.015)
scale(Forest returns03)	−0.078**	0.018	0.525***	0.039***	0.116***	−0.014
	(0.035)	(0.019)	(0.036)	(0.014)	(0.029)	(0.017)
scale(POP03)	−0.239**	−0.043	−0.053	−0.013	0.141	0.016
	(0.121)	(0.068)	(0.127)	(0.023)	(0.300)	(0.034)
scale(Elevation)	−1.452***	−0.189***	−0.754***	−0.139***	−0.859***	−0.108**
	(0.100)	(0.059)	(0.104)	(0.026)	(0.098)	(0.048)
scale(Slope)	−0.429***	−0.135**	0.450***	0.069***	0.017	0.038
	(0.083)	(0.054)	(0.073)	(0.014)	(0.077)	(0.028)
scale(WHC)	0.378***	0.085***	−0.287***	0.014	−0.026	−0.017
	(0.054)	(0.028)	(0.056)	(0.019)	(0.047)	(0.023)
scale(Soil depth)	−0.260***	−0.052*	0.255***	−0.026	0.051	0.006
	(0.053)	(0.028)	(0.055)	(0.019)	(0.049)	(0.023)
scale(Precipitations)	−0.568***	−0.091***	0.040	−0.032***	−0.104***	−0.023
	(0.035)	(0.022)	(0.030)	(0.009)	(0.032)	(0.014)
scale(Temperature)	0.167**	−0.082*	0.151	−0.021	−0.194**	0.039
	(0.084)	(0.046)	(0.093)	(0.018)	(0.084)	(0.033)
scale(Humidity)	−0.003	−0.102***	−0.119*	−0.048***	−0.319***	−0.035
	(0.062)	(0.032)	(0.065)	(0.013)	(0.070)	(0.023)
scale(Radiation)	−0.354***	0.025	−0.650***	−0.018	0.243***	0.019
	(0.074)	(0.037)	(0.081)	(0.021)	(0.078)	(0.034)
Constant	−0.615***	−0.097***	−0.177***	0.060**	−1.815***	−0.082**
	(0.025)	(0.034)	(0.023)	(0.029)	(0.023)	(0.039)
Observations	3,767	3,767	3,767	3,767	3,767	3,767
R^2	0.663	0.911	0.229	0.919	0.359	0.852
Adjusted R^2	0.662	0.911	0.227	0.918	0.357	0.851

Note: *p<0.1; **p<0.05; ***p<0.01.
Reference modality= Pastures, scaled explanatory variables, HC robust standard errors.

3 Estimation results from the GAM model

Table 3: GeoAdditive logit-transformed models of land use on 1993–2003

	Arable Share		Forest Share		Urban Share	
	long run	short run	long run	short run	long run	short run
ARlog93		0.881***				
		(0.010)				
FOlog93				0.912***		
				(0.006)		
URlog93						0.837***
						(0.008)
scale(Arable returns03)	0.403***	0.032*	−0.018	−0.018	0.245***	0.045***
	(0.035)	(0.019)	(0.031)	(0.012)	(0.032)	(0.016)
scale(Pasture returns03)	−0.126***	−0.020	−0.037	−0.016	−0.106***	−0.041***
	(0.033)	(0.018)	(0.029)	(0.011)	(0.030)	(0.015)
scale(Forest returns03)	−0.068*	0.011	0.053	0.021*	0.044	0.022
	(0.041)	(0.020)	(0.037)	(0.013)	(0.037)	(0.018)
scale(POP03)	−0.180***	−0.042***	−0.026	−0.014*	0.141***	0.012
	(0.023)	(0.013)	(0.021)	(0.008)	(0.021)	(0.011)
scale(Elevation)	−1.036***	−0.062	−0.594***	−0.120***	−0.731***	−0.168***
	(0.118)	(0.066)	(0.105)	(0.039)	(0.108)	(0.055)
scale(Slope)	−0.700***	−0.202***	0.453***	0.062***	0.057	0.059**
	(0.062)	(0.034)	(0.055)	(0.021)	(0.056)	(0.029)
scale(WHC)	0.375***	0.062**	−0.233***	0.002	0.0002	−0.013
	(0.051)	(0.028)	(0.046)	(0.017)	(0.047)	(0.024)
scale(Soil depth)	−0.383***	−0.059**	0.097**	−0.030*	−0.057	−0.010
	(0.050)	(0.028)	(0.044)	(0.017)	(0.046)	(0.023)
scale(Precipitations)	−0.486***	−0.084***	0.211***	−0.003	−0.134***	−0.034*
	(0.039)	(0.021)	(0.035)	(0.013)	(0.035)	(0.018)
scale(Temperature)	0.414***	0.025	0.188*	−0.002	0.152	−0.006
	(0.114)	(0.061)	(0.101)	(0.037)	(0.104)	(0.051)
scale(Humidity)	0.028	−0.090**	0.324***	0.022	−0.031	0.040
	(0.067)	(0.036)	(0.060)	(0.022)	(0.061)	(0.030)
scale(Radiation)	−0.118	0.044	−0.442***	0.0002	0.237***	0.070
	(0.097)	(0.051)	(0.086)	(0.031)	(0.088)	(0.043)
Constant	−0.615***	−0.109***	−0.177***	0.047***	−1.815***	−0.107***
	(0.023)	(0.023)	(0.020)	(0.014)	(0.020)	(0.019)
Observations	3,767	3,767	3,767	3,767	3,767	3,767
Adjusted R^2	0.716	0.913	0.426	0.921	0.418	0.855

Note: *p<0.1; **p<0.05; ***p<0.01.
      Reference= Pastures, scaled explanatory variables, bivariate smooth function of coordinates

4 Estimation results from the SEM model

Table 4: Spatial Error Models of land use on 1993–2003

	Arable Share		Forest Share		Urban Share	
	long run	short run	long run	short run	long run	short run
ARlog93		0.889***				
		(0.009)				
FOlog93				0.920***		
				(0.006)		
URlog93						0.842***
						(0.008)
scale(Arable returns03)	0.464***	0.050***	0.031	0.010	0.323***	0.063***
	(0.045)	(0.018)	(0.043)	(0.012)	(0.038)	(0.016)
scale(Pasture returns03)	−0.204***	−0.031*	−0.135***	−0.031***	−0.173***	−0.047***
	(0.049)	(0.017)	(0.047)	(0.012)	(0.039)	(0.015)
scale(Forest returns03)	−0.087*	0.016	0.339***	0.044***	0.116***	−0.005
	(0.051)	(0.016)	(0.053)	(0.011)	(0.038)	(0.015)
scale(POP03)	−0.152***	−0.042***	−0.026	−0.014*	0.124***	0.014
	(0.025)	(0.013)	(0.022)	(0.008)	(0.023)	(0.011)
scale(Elevation)	−1.065***	−0.191***	−0.531***	−0.140***	−0.830***	−0.119***
	(0.099)	(0.045)	(0.090)	(0.029)	(0.086)	(0.039)
scale(Slope)	−0.448***	−0.140***	0.570***	0.071***	0.061	0.044
	(0.066)	(0.032)	(0.059)	(0.020)	(0.059)	(0.027)
scale(WHC)	0.310***	0.084***	−0.195***	0.006	0.017	−0.013
	(0.061)	(0.028)	(0.055)	(0.018)	(0.054)	(0.024)
scale(Soil depth)	−0.213***	−0.049*	0.144***	−0.016	−0.013	0.006
	(0.061)	(0.028)	(0.055)	(0.018)	(0.054)	(0.024)
scale(Precipitations)	−0.510***	−0.095***	0.076	−0.032***	−0.139***	−0.027*
	(0.052)	(0.018)	(0.052)	(0.012)	(0.041)	(0.016)
scale(Temperature)	0.494***	−0.069*	0.422***	−0.004	−0.082	0.041
	(0.110)	(0.040)	(0.107)	(0.027)	(0.089)	(0.035)
scale(Humidity)	0.067	−0.095***	0.140*	−0.041**	−0.272***	−0.036
	(0.083)	(0.030)	(0.082)	(0.020)	(0.067)	(0.027)
scale(Radiation)	−0.267**	0.016	−0.613***	−0.030	0.245***	0.017
	(0.114)	(0.038)	(0.113)	(0.026)	(0.088)	(0.034)
Constant	−0.639***	−0.099***	−0.194***	0.049***	−1.814***	−0.097***
	(0.059)	(0.024)	(0.069)	(0.016)	(0.040)	(0.021)
Observations	3,767	3,767	3,767	3,767	3,767	3,767
σ^2	1.656	0.594	1.250	0.203	1.491	0.394
Akaike Inf. Crit.	12,891.050	8,769.077	11,936.960	4,771.993	12,373.050	7,246.211
Wald Test (df = 1)	1,247.921***	26.557***	880.688***	103.971***	527.874***	65.066***
LR Test (df = 1)	917.587***	12.524***	1,399.780***	96.056***	435.836***	58.226***

Note: *p<0.1; **p<0.05; ***p<0.01
scaled explanatory variables. Reference= Pastures
The Wald and the LR test are the Wald and the likelihood ratio test for the significance of the spatial error coefficient

5 Estimation results from the SXM model

Table 5: Spatial X Models of land use on 1993–2003

	Arable Share		Forest Share		Urban Share	
	long run	short run	long run	short run	long run	short run
ARlog93		0.834***				
		(0.011)				
FOlog93				0.897***		
				(0.006)		
URlog93						0.836***
						(0.009)
scale(Arable returns03)	0.352***	0.077**	−0.054	−0.054***	0.171***	0.048*
	(0.056)	(0.035)	(0.049)	(0.020)	(0.054)	(0.029)
scale(Pasture returns03)	−0.032	0.004	−0.010	0.034	−0.022	−0.029
	(0.068)	(0.042)	(0.060)	(0.024)	(0.066)	(0.034)
scale(Forest returns03)	−0.035	0.011	0.074	0.043	0.066	0.124***
	(0.093)	(0.057)	(0.081)	(0.033)	(0.090)	(0.047)
scale(POP03)	−0.132***	−0.016	−0.020	−0.010	0.123***	0.011
	(0.025)	(0.016)	(0.022)	(0.009)	(0.024)	(0.013)
scale(Elevation)	−0.857***	−0.053	−0.512***	−0.092**	−0.844***	−0.133**
	(0.105)	(0.067)	(0.093)	(0.038)	(0.101)	(0.054)
scale(Slope)	−0.432***	−0.154***	0.578***	0.076***	0.046	0.068**
	(0.067)	(0.042)	(0.059)	(0.024)	(0.063)	(0.034)
scale(WHC)	0.238***	0.047	−0.188***	−0.027	0.013	−0.001
	(0.064)	(0.040)	(0.057)	(0.023)	(0.062)	(0.033)
scale(Soil depth)	−0.180***	−0.014	0.132**	0.013	−0.044	−0.001
	(0.063)	(0.039)	(0.055)	(0.023)	(0.060)	(0.032)
scale(Precipitations)	−0.200**	−0.020	0.197***	0.005	−0.155*	−0.066
	(0.083)	(0.051)	(0.073)	(0.030)	(0.080)	(0.042)
scale(Temperature)	1.017***	0.283***	0.307**	0.041	0.379**	0.021
	(0.161)	(0.101)	(0.141)	(0.059)	(0.156)	(0.083)
scale(Humidity)	−0.225	−0.148*	0.209*	0.020	−0.062	0.023
	(0.138)	(0.084)	(0.120)	(0.049)	(0.133)	(0.069)
scale(Radiation)	−0.277	−0.080	−0.546***	−0.013	0.176	0.108
	(0.176)	(0.108)	(0.153)	(0.063)	(0.170)	(0.089)
Constant	−0.638***	−0.116***	−0.191***	0.074**	−1.814***	0.001
	(0.055)	(0.043)	(0.061)	(0.029)	(0.039)	(0.040)
Observations	3,767	3,767	3,767	3,767	3,767	3,767
σ^2	1.616	0.572	1.244	0.197	1.476	0.390
Akaike Inf. Crit.	12,802.470	8,650.725	11,900.890	4,673.891	12,353.180	7,225.390

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
scaled explanatory variables. Reference= Pastures

6 Estimation results from the SAR model

Table 6: Spatial Autoregressive Regressions of land use on 1993–2003

| | Arable Share | | Forest Share | | Urban Share | |
	long run	short run	long run	short run	long run	short run
ARlog93		0.854***				
		(0.010)				
FOlog93				0.890***		
				(0.007)		
URlog93						0.830***
						(0.009)
scale(Arable returns03)	0.297***	0.017	0.069***	−0.005	0.242***	0.034**
	(0.028)	(0.015)	(0.024)	(0.010)	(0.029)	(0.015)
scale(Pasture returns03)	−0.145***	−0.002	−0.110***	−0.010***	−0.132***	−0.029**
	(0.026)	(0.005)	(0.023)	(0.003)	(0.024)	(0.013)
scale(Forest returns03)	−0.040	0.028*	0.170***	−0.0001	0.067***	−0.016
	(0.025)	(0.017)	(0.022)	(0.010)	(0.024)	(0.019)
scale(POP03)	−0.164***	−0.037***	−0.026	−0.011	0.113***	0.010
	(0.022)	(0.013)	(0.018)	(0.008)	(0.021)	(0.011)
scale(Elevation)	−0.652***	−0.069	−0.460***	−0.132***	−0.564***	−0.063*
	(0.075)	(0.043)	(0.057)	(0.024)	(0.076)	(0.038)
scale(Slope)	−0.309***	−0.116***	0.357***	0.069***	0.029	0.045*
	(0.051)	(0.030)	(0.039)	(0.019)	(0.067)	(0.027)
scale(WHC)	0.197***	0.053**	−0.146***	0.026	−0.027	−0.021**
	(0.046)	(0.026)	(0.039)	(0.016)	(0.034)	(0.010)
scale(Soil depth)	−0.131***	−0.028	0.117***	−0.038**	0.031	0.006
	(0.046)	(0.026)	(0.039)	(0.017)	(0.056)	(0.010)
scale(Precipitations)	−0.248***	−0.038**	−0.005	−0.040***	−0.063*	−0.014
	(0.030)	(0.017)	(0.010)	(0.010)	(0.037)	(0.012)
scale(Temperature)	0.064	−0.090**	0.072*	−0.027	−0.143**	0.050***
	(0.078)	(0.036)	(0.040)	(0.026)	(0.060)	(0.017)
scale(Humidity)	−0.094*	−0.117***	0.034	−0.026	−0.209***	−0.015**
	(0.057)	(0.027)	(0.028)	(0.019)	(0.050)	(0.006)
scale(Radiation)	−0.157**	0.042	−0.296***	0.012	0.143**	−0.011
	(0.071)	(0.035)	(0.043)	(0.027)	(0.063)	(0.010)
Constant	−0.275***	−0.036	−0.058***	0.053***	−0.982***	0.081***
	(0.024)	(0.023)	(0.019)	(0.013)	(0.043)	(0.029)
Observations	3,767	3,767	3,767	3,767	3,767	3,767
σ^2	1.721	0.580	1.265	0.201	1.513	0.396
Akaike Inf. Crit.	12,962.830	8,684.350	11,939.190	4,694.791	12,403.390	7,243.951
Wald Test (df = 1)	1,091.723***	106.356***	2,162.109***	207.793***	479.396***	69.676***
LR Test (df = 1)	845.807***	97.251***	1,397.558***	173.258***	405.499***	60.486***

Note: *p<0.1; **p<0.05; ***p<0.01
scaled explanatory variables. Reference= Pastures
The Wald and the LR test are the Wald and the likelihood ratio test for the significance of the spatial lag coefficient

7 Estimation results from the SDM model

Table 7: Spatial Durbin Models of land use on 1993–2003

	Arable Share		Forest Share		Urban Share	
	long run	short run	long run	short run	long run	short run
ARlog93		0.831***				
		(0.009)				
FOlog93				0.893***		
				(0.006)		
URlog93						0.834***
						(0.008)
scale(Arable returns03)	0.342***	0.079***	−0.119***	−0.055***	0.148**	0.048**
	(0.050)	(0.027)	(0.010)	(0.017)	(0.058)	(0.024)
scale(Pasture returns03)	0.005	0.004	0.042	0.033***	−0.015	−0.029***
	(0.014)	(0.014)	(0.014)	(0.004)	(0.030)	(0.011)
scale(Forest returns03)	−0.031	0.011	−0.039	0.044	0.036	0.126***
	(0.048)	(0.048)	(0.048)	(0.037)	(0.052)	(0.048)
scale(POP03)	−0.100***	−0.016	−0.011	−0.011	0.115***	0.009
	(0.029)	(0.029)	(0.029)	(0.008)	(0.021)	(0.014)
scale(Elevation)	−0.768***	−0.052	−0.476***	−0.094	−0.831***	−0.137*
	(0.111)	(0.085)	(0.097)	(0.070)	(0.120)	(0.076)
scale(Slope)	−0.443***	−0.155	0.603***	0.076***	0.055	0.067
	(0.070)	(0.070)	(0.058)	(0.012)	(0.098)	(0.048)
scale(WHC)	0.226***	0.047	−0.165	−0.027	0.028	−0.003
	(0.070)	(0.070)	(0.070)	(0.070)	(0.063)	(0.063)
scale(Soil depth)	−0.176***	−0.014	0.106	0.014	−0.065	0.001
	(0.065)	(0.065)	(0.065)	(0.065)	(0.067)	(0.002)
scale(Precipitations)	−0.203***	−0.022	0.239***	0.006	−0.129*	−0.068***
	(0.055)	(0.052)	(0.052)	(0.052)	(0.074)	(0.026)
scale(Temperature)	1.086***	0.286	0.376***	0.050	0.399***	0.009
	(0.160)	(0.119)	(0.138)	(0.119)	(0.119)	(0.119)
scale(Humidity)	−0.211	−0.147***	0.301***	0.026	−0.026	0.033
	(0.136)	(0.018)	(0.036)	(0.060)	(0.060)	(0.065)
scale(Radiation)	−0.206	−0.080	−0.541***	−0.019	0.189	0.113
	(0.171)	(0.171)	(0.158)	(0.171)	(0.171)	(0.073)
Constant	−0.242***	−0.109***	−0.058***	0.061	−0.929***	0.013
	(0.023)	(0.019)	(0.017)	(0.019)	(0.044)	(0.028)
Observations	3,767	3,767	3,767	3,767	3,767	3,767
σ^2	1.619	0.571	1.236	0.197	1.476	0.389
Akaike Inf. Crit.	12,803.420	8,648.834	11,865.140	4,671.029	12,349.980	7,223.800
Wald Test (df = 1)	1,278.793***	4.324**	2,047.633***	69.960***	516.272***	49.006***
LR Test (df = 1)	904.656***	4.175**	1,307.732***	68.563***	424.817***	47.962***

Note: *p<0.1; **p<0.05; ***p<0.01
on scaled explanatory variables. Reference= Pastures
The Wald and the LR test are the Wald and the likelihood ratio test for the significance of the spatial lag coefficient

8   Maps at the aggregated scale
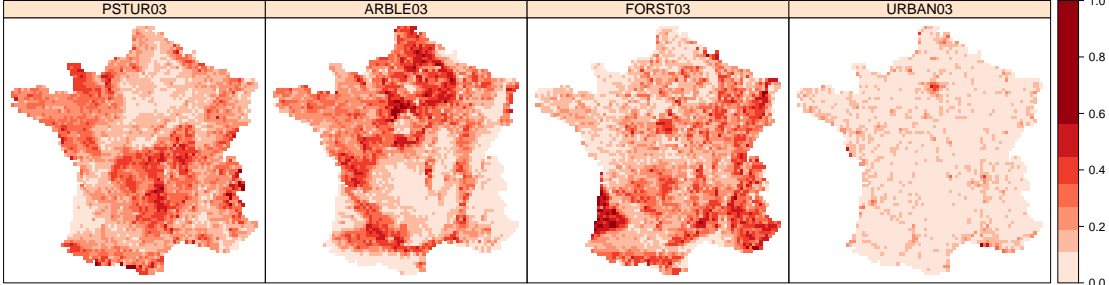
Figure 1: Aggregated land use shares in 2003

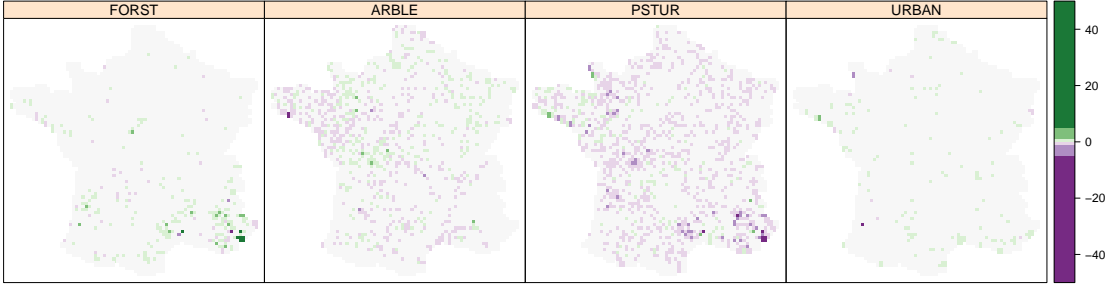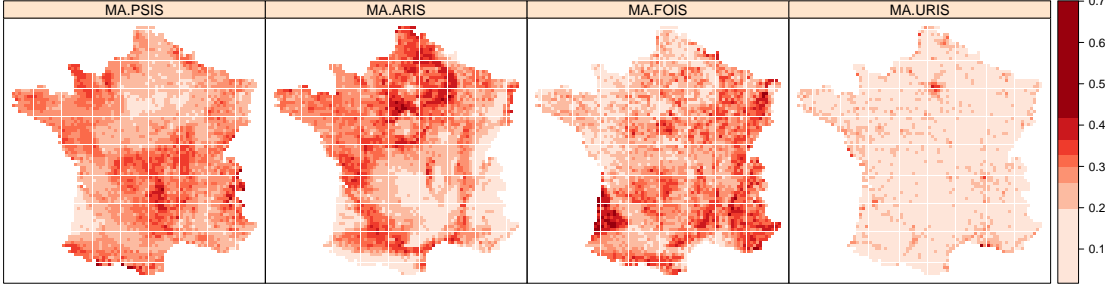**Figure 2:** Aggregated land use variations on 1993–2003, in km^2

Figure 3: Out of sample 2003 predictions from individual mnl

9 Aggregated outcome variables

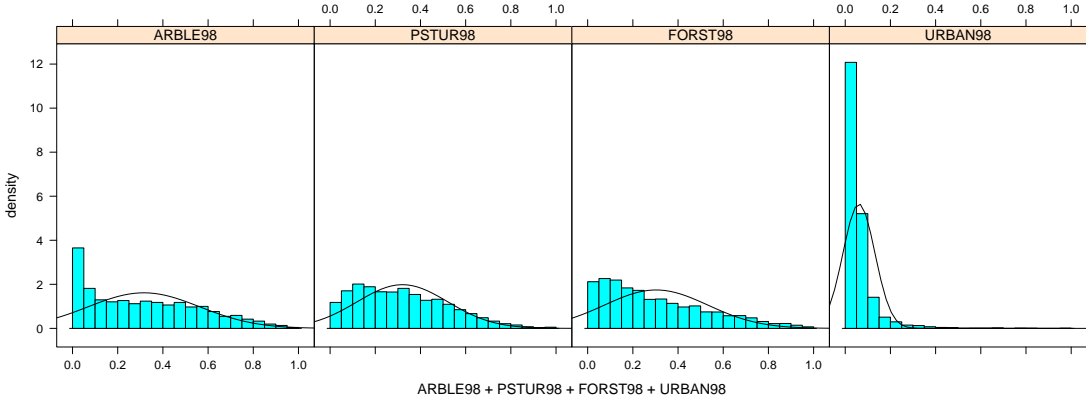**Figure 4:** Raw distribution of 1998 aggregated land use shares

Figure 5: Linearized distribution of 1998 aggregate land use shares