ESTIMATION OF A DISCRETE-CHOICE MODEL WITH SPATIAL INTERACTIONS: THE CASE OF DEFORESTATION IN WESTERN ATTICA BETWEEN 1990 AND 2000

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Abstract
This paper presents an environmental application, investigating land use changes of forests and semi-natural areas in the Greek region of Western Attica. Its objective is to estimate the spatial equilibrium distribution of individual deforestation actions and determine the degree of coordination in individual behaviour. For this purpose, the paper starts by creating a virtual economic network of 156 agents, by laying an ad hoc square grid over the region. Next, the dominant forest land use changes have been determined for each land parcel, using CORINE land cover maps for the years 1990 and 2000. The economic model used is a discrete choice model, with endogenous spatial interactions. Even though spatial interactions produce multiple equilibria, the present research proposes a two-stage fixed point estimator, yielding a unique solution. Empirical findings suggest that equilibrium deforestation actions are strategic substitutes for the environment and complements for agriculture, and are characterized by a relative lack of coordination in individual behaviour.

Keywords: *land use change, spatial interaction, discrete choice modeling, deforestation*
JEL classification: **R10, R11.**

1. Introduction

Forests belong to an economy's physical capital and, as such, are endogenous to its economic growth rate. Despite the fact that Greek forests are public goods, protected by the constitution, the myopic pursuit of private interest in conflict with environmental welfare has led to systematic clearing of forest land located near urban, agricultural and industrial areas. According to geographical and census data concerning the Attica region in 1990 and 2000, land use changes that took place in Western Attica indicate forest clearing in favor of economic activities. These changes are the result of thriving economic activity in the region during 1990-2000, characterized by a relative lack of appropriate urban planning.

The purpose of this article is to study the strategic deforestation behaviour of individuals active in Western Attica between 1990 and 2000 and determine the degree of coordination of individual actions. In this respect, it proposes an alternative estimation method of a discrete choice model with endogenous spatial interactions, which belongs to the general class of social interactions models (Brock and Durlauf [5], [6], [7]) and has been applied in a spatial study investigating tropical deforestation in Costa Rica, where forest land is governed by individual property rights (Robalino and Pfaff [14]). The economy is a network of a finite number of interacting individuals, whose strategic actions produce spatial spillovers. The decision-making process is decentralized and has the form of a static spatial deforestation game, with complete but imperfect information, implying that individuals know ex ante the optimal strategy of their nearest neighbours up to the parameters, which determine its shape. Even though social models with local interactions produce multiple equilibria, the present paper combines fixed point theory with a statistical theorem on social networks, allowing the estimation of a unique equilibrium.

2. Methodology

2.1. The deforestation game

The spatial effects investigated in the present research paper are net environmental and agricultural externalities, arising in the context of a decentralized interdependent decision-making process. In principle, such effects arise in a decentralized economy with multiple equilibria as a result of failure to coordinate individual strategic actions (Cooper and John [9]). In particular, individual strategies produce positive (negative) externalities or spillovers, and are hence considered strategic complements (substitutes), when a positive change in an individual's strategic action increases (decreases) the strategic reactions of the other individuals.

However, non-cooperative action is characterized by spillover symmetry across individuals, implying that an individual's optimal strategic action ignores half the spillovers induced by his choice because he does not internalize the spillovers induced by his behaviour (Brock and Durlauf [6]). Equilibrium strategic actions are socially efficient in a socially planned economy, because individual action accounts for the spillovers induced by the impact of individual actions on mean behaviour. Thus, when individuals optimally choose to clear forest land without coordination (NC,NC), the spatial interaction effect should be half its magnitude than under full coordination (C,C) hence socially inefficient.

Table 1: Normal form of the deforestation game with spatial interactions

		Optimal reaction of individual *i*'s nearest neighbours	
		Do not clear forest land (C)	Clear forest land (NC)
Optimal reaction of the i^{th} individual	Do not clear forest land (C)	(C,C) $\rightarrow \rho_{00} > 0$ (ESC)	(C,NC) $\rightarrow \rho_{01} < 0$ (ASS)
	Clear forest land (NC)	(NC,NC) $\rightarrow \rho_{10} < 0$ (ESS)	(NC,NC) $\rightarrow \rho_{11} > 0$ (ASC)
	Net spatial effect	Environmental $\rho_0 = \rho_{00} + \rho_{10}$	Agricultural $\rho_1 = \rho_{01} + \rho_{11}$

Notes. C stands for cooperation (coordination); NC stands for non-cooperation (lack of coordination).

According to Table 1, four types of spatial effects may be distinguished: Environmental Strategic Complementarities (ESC) and Substitutes (ESS), and Agricultural Strategic Complementarities (ASC) and Substitutes (ASS). For instance, ESS arise when neighbours have incentive to use land near forest for industrial development; ASC arise when farmers as a group improve their bargaining position by buying inputs to clear forest land and selling output produced on cleared land at better prices; and ASS arise when reduced local agricultural prices are the result of neighbour forest clearing for the production of agricultural goods (Robalino and Pfaff [14]).

2.2. The economic model

The economy consists of a finite number of homogeneous interacting individuals i = 1,2,. . .,I with attributes xi. The decision-making process is decentralized. Each individual is faced with the binary choice yi $\in \{0,1\}$ to clear (yi = 1) or not (yi = 0) forest land. The binary event yi, is an independent and identically distributed (i.i.d.) Bernoulli variable. Individuals have the same number of nearest neighbours' |Ni|, implying regular interactions. Moreover, individuals form expectations regarding nearest neighbours' optimal reaction as a function of the latter's spatial location. Expectations are rational, hence realized actions equal their expected values in equilibrium: yij $\equiv$ Ei (yj) = E(yj) for every i and every j$\in$Ni. Individual strategies take the form of profit functions additive in deterministic private, deterministic social and stochastic private profit:

$$\Pi_i(y_i) \equiv \pi_i(y_i, x_i) + \pi_i^S \left(y_i, x_i, \mathrm{E}(y_j) \right) + \varepsilon_i(y_i) \quad (1)$$

In particular, equations 2-3 below describe the cases of deforestation and non-deforestation, respectively:

$$\Pi_i(y_i = 1) \equiv x_i^{'}\beta + \rho_{11} \sum_{j \in N_i} w_{ij}\mathrm{E}(y_j) + \rho_{10}\left(1 - \sum_{j \in N_i} w_{ij}\mathrm{E}(y_j)\right) + \varepsilon_i(1) \quad (2)$$

$$\Pi_i(y_i = 0) \equiv x_i^{'}\beta + \rho_{01} \sum_{j \in N_i} w_{ij}\mathrm{E}(y_j) + \rho_{00}\left(1 - \sum_{j \in N_i} w_{ij}\mathrm{E}(y_j)\right) + \varepsilon_i(0) \quad (3)$$

The spatial structure is fixed. It is described by spatial weight matrix W with non-zero off-diagonal elements $0 \leq wij \leq 1$, denoting the proportion of land owned by neighbour j in individual i's neighbourhood. As a result, the summand denotes the area of individual i's neighbourhood that has been cleared. By assumption, individual errors are jointly independent standard normal or extreme value type I (or log-Weibull) distributed, hence error differences will be standard normal (whether individual errors are mutually independent or not) or logistic distributed, respectively. Defining $\varepsilon_i \equiv \varepsilon_i(1) - \varepsilon_i(0)$ and $\beta \equiv \beta 1 - \beta 0$, each individual has an incentive to clear forest land if clearing yields a net positive profit:

(4)

Parameters ρ0 and ρ1 are the net spatial interactions of Table 1. The individual strategic deforestation likelihood is defined as follows:

$$\Pr(y_i = 1) = \Pr(\Delta\Pi_i > 0) = \mathrm{F}(\varepsilon_i = 1) \equiv P_i \quad (5)$$

Indicator function $yi = 1\{\Delta\Pi i > 0\}$ summarizes the actual deforestation action, and F is a given continuous and strictly increasing distribution function, such as the standard normal or the logistic one. Individual likelihoods, Pi, make up a simultaneous system of I equations with solution equal to the probability distribution, P, which corresponds to the economy's equilibrium. Since expectations are rational by assumption, the equilibrium will be self-consistent and the system will be characterized by coherency or internal consistency. In particular:

$$y_{ij} = \mathrm{E}_i(y_j) = E(y_j) = P_j \;\; \forall j \in N_i \;\; \text{and} \;\; \forall i \in I \quad (6)$$

The fact that each element of vector P is indexed by subscript j implies that individual expectations regarding nearest neighbours' optimal reactions are a function of the latter's spatial location. According to the topology of spatial interactions (Ioannides [11]), when individuals are distinguished by their location in space, the resulting equilibria are anisotropic, as opposed to isotropic ones resulting from global interactions describing the mean filed case, where a single individual's choice automatically determines the choices of all other individuals (Brock and Durlauf [5], Blume et al. [4]). Anisotropy implies clustering hence multiple equilibria (e.g. Tamer [17]). However, uniqueness of equilibrium is possible as long as the system is fully recursive hence internally consistent (Ioannides [11], Blume et al. [4]). When interactions are spatial, the system is fully recursive when each individual's neighbourhood has the topological structure of a clique. A clique is consisting of a set of sites, in which are all neighbours to each other (Cressie [9]). For instance, triangle or hexagons (with all edges mutually connected) are examples of cliques!

2.3. The spatial interactions matrix

The proposed spatial interactions matrix $W(I,1)$, is a function of the first order rook contiguity criterion $\Gamma(I,1)$. Rook contiguity is inspired by the moves of the rook in a chess game (Anselin [2]). Its algebraic representation has the form of a symmetric contiguity matrix $\Gamma(I,p)$, with connectivity order p. When $p = 1$, individuals are rook-contiguous with two adjacent neighbours giving rise to a linear adjacency pattern, hence $N_i = \{i-1, i+1\}$ and $|N_i| = 2$ for every i. Nevertheless, $\Gamma(I,1)$ is not fully recursive in the sense of a clique. Defining the off-diagonal elements of $\Gamma(I,1)$ as $\{\gamma_{ij}\} = \{1|i-j \leq 1|\}$ and those of $W(I,1)$ as $\{w_{ij}\} = \{(1/\lambda I) \times \min(i,j) \times \gamma_{ij}\}$ with $\lambda = p = 1$, Table 2 below describes the proposed spatial interactions structure for $I \geq 4$:

According to W(I,1), each individual landowner interacts with its two adjacent neighbours, forming a linear adjacency pattern. Moreover, the relative weight of neighbours' expected deforestation action increases with network size, hence with spatial location. Roughly speaking, spatial interactions grow stronger with network size.

Table 2: Algebraic representation of first-order rook interaction

Contiguity matrix W(I,1)					*Interactions matrix Γ(I,1)*				
0	1	0	0	…	0		0	0	…
1	0	1	0	…	$1/\lambda I$	0	$2/\lambda I$	0	…
0	1	0	1	…	0	$2/\lambda I$	0	$3/\lambda I$	…
0	0	1	0	…	0	0	$3/\lambda I$	0	…
…	…	…	…	…	…	…	…	…	…

2.4. The econometric model

The econometric model is a discrete choice model with endogenous spatial interactions, which has the form of a dynamic system of I simultaneous equations, each one describing individual expected deforestation action (Equation 5). It is specified as follows:

$$P_i = F\left(x_i'\beta + (\rho_0 + \rho_1)\sum_{j \in N_i} w_{ij}P_j - \rho_0\right) \tag{7}$$

$$\sum_{j \in N_i} w_{ij}P_j = \sum_{j \in N_i} w_{ij}F\left(x_j'\beta + (\rho_0 + \rho_1)\sum_{k \in N_j} w_{jk}P_k - \rho_0\right) \tag{8}$$

Equation (8) serves as a selection mechanism implying that neighbours' expected deforestation actions are endogenously determined in a recursive way. Although group formation is endogenous (Moffitt [13]), its mechanism is known ex ante, since interactions matrix W, attributes x, and the parametric form of distribution F, are given.

In general, such a model is identified non-parametrically, as long as the attributes defining the reference groups (Equation 8) and those directly affecting outcomes (Equation 7) are 'moderately' related random variables, excluding the extreme cases of statistical (or functional) independence and perfect linear relationships (Manski [12]). Identification is improved if the functional form is non-linear in a way that generates multiple social equilibria[7]. A parametric binary response model with endogenous effects, such as the proposed spatial interactions model, is such a case. Identification is owed to the following three facts: (a) its functional form is non-linear; (b) the parametric form of distribution function F derives from the exponential family (standard normal or logistic), hence it is continuous and strictly increasing; and (c) $W \neq I$ (here I denotes the identity matrix) implies that there is sufficient variability in endogenous variable WP, hence spatial interactions and the possibility of multiple equilibria improve identification.

Moreover, the parametric binary response model with endogenous effects is coherent hence there exists a solution to the system. The uniqueness or multiplicity of the solution depends on the sign of the endogenous parameter (Manski [12], Gourieroux [10]). When the endogenous parameter is negative, the estimated equilibrium will be unique and the estimated probability distribution of individual expected deforestation actions will have a single intersection with that of their nearest neighbours' in the open interval (0,1). In other words, as the distribution function of individual expected actions traverses the closed interval [0,1], their neighbours' will be continuously and strictly decreasing in (0,1), crossing the former once from below. On the other hand, when the endogenous parameter ρ is strictly positive, the distribution function of neighbours' expected deforestation actions will be continuously and strictly increasing in (0,1), crossing that of the individuals from above (cf. Figure 1). However, the number of equilibria cannot be determined in that case, unless additional structure is imposed on the model. In the present context, spatial interactions matrix W provides the required structure, while uniqueness is achieved by means of the estimation method.

2.5. Fixed-point estimation

When the interactions are spatial, the joint probability distribution of the realized values of the Bernoulli random variable is a Markov Random Field (MRF) defined on the event set as a function of the set of the spatial sites where the latter is observed. According to the Hammersley-Clifford Theorem, as long as the MRF has the property of conditional independence, the joint probability measure has a unique representation in terms of consistent conditional probabilities defining a neighbourhood structure described by a given factor graph defined as $G = \{y_{ij} : i \neq j, 1 \leq i, j \leq g\}$[8]. Uniqueness implies a fully-recursive system (clique) which is very restrictive. When the data are discrete and the spatial dependence pairwise ($g = 2$), Pr(G) is logistic (exponential family). Hence, knowledge of the parametric form, F, is equivalent to knowledge of the joint itself up to a constant c:

$$\Pr(y) = c\exp F(y) \;\; \forall y \in \zeta \text{ or } \Pr(y) \propto \exp F(y) \qquad (9)$$

As long as c is of known functional form, and finitely summable, F may be used for maximum likelihood estimation purposes. However, the presence of c complicates exact maximum likelihood estimation (MLE) of Equation 9[9]. Maximum Pseudo-Likelihood estimation (MPLE) instead is feasible and computationally simpler, since it avoids estimation of c. It relies on the existence of a 1-1 correspondence between graph models and logit models, which are uniquely identified (Strauss and Ikeda [16]). In fact, MPLE is equivalent to exact MLE of the logistic regression for independent observations. Bootstrap errors are required to correct for both the spatial dependence of the right hand side variables and the relative inefficiency owed to the use of the pseudo-likelihood.

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7 The linear version of the social model with endogenous effects (the linear-in-means model) fails to identify the endogenous parameter when the latter incorporates a social equilibrium condition, hence the reflection problem (Manski, 1993).

8 According to the Hammersley-Clifford Theorem, a spatial site *j* is a neighbour of site *i*, when the MRF has the Markovian property of conditional independence, i.e. when the joint probability measure may be uniquely factorized in terms of consistent factors defining a fully recursive neighbourhood structure i.e. a clique (Cressie [9]).

9 Estimation of c is intractable for higher orders of dependence, namely for $g \geq 6$.

Furthermore, taking into account the endogeneity of individual expected deforestation action and the recursive nature of the model, the equilibrium probability distribution of deforestation P(θ), is indirectly determined as the fixed point of a real mapping, Ψ, in probability space, hence it is a Brouwer fixed point[10]. As a result, defining $\rho \equiv \rho 0 + \rho 1$ and $\theta \equiv (\beta', \rho')$, and assuming that xi includes a constant, Equation 7 is the individual pseudo-likelihood for estimation purposes:

$$P_i = F\left(x_i^{'}\beta + \rho w_{i\_}^{'}P\right) \qquad (10)$$

Hence, the fixed-point mapping of the network:

$$P = F(X\beta + \rho WP) = \Psi(P(\theta), \theta) \qquad (11)$$

According to the empirical literature, discrete choice models with endogenous effects are estimated in two stages (see for instance, Robalino and Pfaff [14]). The present research study proposes a two-stage fixed point estimator (Aguirregabiria [1]), with bootstrap errors instead. Given initial values for θ and P and $r \geq 1$ iterations, the estimator (FXP2S) is a two-step fixed-point algorithm maximizing the logarithm of the binary probit pseudo-likelihood over all network individuals:

$$\sum_i \ln P_i = \sum_i \ln\Psi(y_i|\theta) = \sum_i \{y_i \ln\Psi(P(\theta), \theta) + (1 - y_i)\ln\Psi_C(P(\theta), \theta)\} \qquad (12)$$

$$\text{Estimation stage 1: } \hat{\theta}_I^r = \text{argmax}_{\theta\in\Theta} \sum_i \ln\Psi\left(y_i|\hat{P}_I^{r-1}, \hat{\theta}_I^{r-1}\right) \qquad (13)$$

$$\text{Estimation stage 2: } \hat{P}_I^r = \Psi\left(y|\hat{P}_I^{r-1}, \hat{\theta}_I^{r-1}\right) \qquad (14)$$

The initial value of P is estimated on the basis of a binary probit model without spatial interactions. The estimator sequence satisfies consistency and asymptotic normality.

Tables 3 and 4 report Monte Carlo simulation results for the proposed estimator, with a single exogenous regressor, given the proposed spatial weight matrix W. The sample size is kept relatively small in order to mimic the size of the network used in the empirical part. In fact, a square grid with cell size 3km x 3km produces 156 observations and explains the land use changes under investigation relatively well, whereas a square grid with cell size 1.5km x 1.5km produces 526 observations, but is relatively unstable in terms of estimation[11]. Unless (QML) standard errors are corrected for the spatial asymptotic bias, owed to the spatial dependence of the right hand side variables[12], inference will not be reliable.

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[10] The underlying statistical model belongs to a family of parametric distributions, $\{P(\theta)\}$, whose members are continuous one-to-one mappings defined on standard unit interval $[0,1]^I$. In particular, $\Psi: F \times \Theta \rightarrow F$ is the fixed point mapping and Θ is the compact and convex parametric space.

[11] Results are not reported here.

[12] Recall that the data generating process (dgp) is spatial hence the spatial dependence and asymptotic bias.

Table 3: Monte Carlo simulation results

Variable	Parameter value	Sample size	Estimate	RMSE	$\overline{P}_0$	$W\overline{P}_0$
Constant	$\rho_0=0$	100	0.010	0.245	0.617076	0.124504
		150	0.002	0.188	0.694235	0.221352
		200	0.005	0.171	0.714301	0.315057
		300	–0.006	0.148	0.793097	0.531006
		400	–0.003	0.146	0.845843	0.751273
(Exogenous regressor) X_1	$\beta=1$	100	1.051	0.223	0.617076	0.124504
		150	1.052	0.192	0.694235	0.221352
		200	1.035	0.173	0.714301	0.315057
		300	1.027	0.153	0.793097	0.531006
		400	1.025	0.153	0.845843	0.751273
(Endogenous regressor) P	$\rho=3$	100	3.009	1.593	0.801371	0.430272
		150	3.099	0.783	0.694235	0.221352
		200	3.072	0.560	0.714301	0.315057
		300	3.090	0.429	0.793097	0.531006
		400	3.079	0.398	0.845843	0.751273

Notes: #Simulations = 1000. $W(I,1)$: $\{w_{ij}\} = \{(\min(i,j)/500)\times(1|i-j\leq 1|)\}$. RMSE = Root Mean Square Error.

The results suggest that the asymptotic bias varies with sample size (Table 3) and number of nearest neighbours[13] (Table 4) given the proposed spatial weight matrix W. Sample sizes between 150 and 300 observations respond relatively better, both in terms of bias and RMSE (Table 3). Nonetheless, a bootstrap correction with 100 draws resolves the issue (cf. empirical application, next). The initial level of P is indicative of the degree of identification. Although the initial level of P increases with sample size, a weighted initial value (WP) between 0.2 and 0.3 is adequate (Table 3).

Table 4: Monte Carlo simulation results

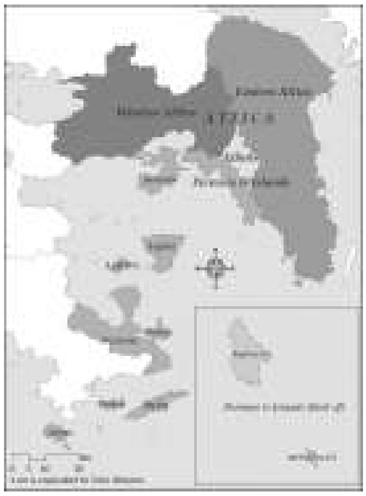
Sample size = 150		# Nearest neighbours $p=1$				# Nearest neighbours $p=2$			
Variable	Parameter value	Estimate	RMSE	$\overline{P}_0$	$W\overline{P}_0$	Estimate	RMSE	$\overline{P}_0$	$W\overline{P}_0$
Constant	$\rho_0=0$	0.002	0.188	0.694235	0.221352	–0.014	0.216	0.839990	0.545561
X_1	$\beta=1$	1.052	0.192	0.694235	0.221352	1.067	0.241	0.839990	0.545561
P	$\rho=3$	3.099	0.783	0.694235	0.221352	3.211	0.676	0.839990	0.545561

Notes. #Simulations = 1000. $W(Ip)$: $\{w_{ij}\} = \{(\min(i,j)/500)\times(1|i-j\leq p|)\}$. RMSE = Root Mean Square Error.

[13] Given the rook definition of W, the spatial pattern remains linear despite the number of nearest neighbours.

3. Empirical Application

The empirical part investigates the degree of deforestation in the Greek region of Western Attica (Maps 1-2) between 1990 and 2000. The sample is a square lattice of 156 land parcels, constructed by laying a square grid with cell size 3km x 3km over the European Environmental Agency's (EEA) CORINE Land Cover (CLC) maps for the years 1990 and 2000 (Besag [3], Strauss [15]). CORINE Land Cover maps for the years 1990 and 2000 have been derived using visual interpretation of Landsat TM and ETM+ imagery (100m resolution). The cell size of the proposed square lattice captures relatively well both actual land uses as well as sample and estimated land use changes. Finer grids, say a cell size of 1.5km x 1.5km, produce noisy estimates. Administrative boundaries are at the level of municipalities according to the 'Kapodistrias'[14] project (Map 3).

Maps 1 and 2: Geographic location and regional division of Attica (left-right)

Western Attica is located west of the Attica region, which in turn is located at the center of Greece (Map 1), and is divided in four regions: Western Attica, Eastern Attica, Athens (Capital City) and Peiraias & Islands (Map 2). Western Attica consists of 12 municipalities: Elefsina, Ano Liosia, Aspropyrgos, Vilia, Erythres, Zefyri, Mandra, Megara, New Peramos, Fyli[15], Magoula and Oinoi (Map 3). Elefsina, Aspropyrgos, Mandra and Magoula constitute the Thriasio field. The broader area of Thriasio, Megara and New Peramos constitutes the Southern region (Map 4). Moreover, four sectors may be distinguished: the Attica County (Ano Liosia-Zefyri-Fyli), Thriasio, Megara-New Peramos, and Erythres-Vilia-Oinoi (Map 5). Some of the country's most significant industrial and commercial activities are concentrated in Thriasio, such as the Oil refinery of Aspropyrgos (Map 5), various steel industries (e.g. TITAN, the Hellenic Steel Industry), and the commercial port of Aspropyrgos. Unless economic agents internalize the environmental cost of their activities in the form of regular investment in environmental protection technology, such as bio-cleaning units and filters, environmental risks are imminent and high.

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14 'Kapodistrias' project: an administrative reform that took place in 1997, redefining the boundaries of the administrative units of Greek municipalities.

15 Fyli is a semi-mountainous area (Mount Fyli is located West of Mount Parnitha) known, among others, for the historic site of the Fyli Castle (located at an altitude of 687m). The Ancient-Greek municipality of Fyli relied on the Castle for the defense of Athens against Thebans and other enemies.

Another source of pollution has been the nearby dump site in Ano Liosia (Map 5, Attica County), which served until 2011 as one of the Capital City's major landfills[16].

3.1. Demographic and other attributes

Western Attica covers a total area of 1004 km^2. According to the 2001 census, the total population of the region increased from 124,752 inhabitants in 1991 to 151,612 in 2001, an increase of 21% (Table 5). The largest part of the population is concentrated in Thriasio (53,963 or 43.3% in 1991; 70,401 or 46.4% in 2001) and the Southern region (85,893 or 68.9% in 1991; 106,076 or 70% in 2001). The population growth is mainly owed to the large concentration of economic activities in Thriasio, which raised the demand for labor and attracted workers from other Greek regions. Moreover, the relatively lower housing and land costs in municipalities located at the borders of the Capital City, such as Ano Liosia and Aspropyrgos, provided movers with additional incentives. However, the population growth was not followed by appropriate urban development.

Maps 3-4-5: Administrative, regional and sectoral division of Western Attica

Table 5: Demographic attributes and area

Municipality	Area (km^2)	Population 1991	2001	Change	Population Type 2001	Urbanization 1991	2001
Elefsina	18.94815	22,793	25,863	13.5%	P	U	U
Ano Liosia	38.45574	21,397	26,423	23.5%	SM	U	U
Aspropyrgos	100.83685	15,715	27,741	76.5%	P	U	U
Vilia	142.90266	3,412	3,215	-5.8%	M	R	R
Erythres	60.70775	3,519	3,326	-5.5%	P	SU	U
Zefyri	1.28169	8,985	8,860	-1.4%	P	SU	U
Mandra	206.42451	11,343	12,792	12.8%	SM	U	U
Megara	325.79843	25,061	28,195	12.5%	SM	U	U
N. Peramos	7.56726	6,869	7,480	8.9%	P	SU	U
Fyli	69.17546	2,925	2,947	0.8%	SM	SU	U
Magoula	18.17478	2,663	4,005	50.4%	P	SU	U
Oinoi	13.77090	495	765	54.5%	SM	R	R
Total	1,004.04418	124,752	151,612	21.5%			

Notes: SM stands for Semi-Mountainous, M for Mountainous, P for Plain, R for Rural and U for Urban. A municipality is classified as urban when its most populated dwelling has ≥ 2,000 inhabitants and as rural otherwise.

[16] The dump site in Ano Liosia operated as an uncontrolled landfill until 2007. However, despite the lack of immediate alternatives, it continued its operation until 2011. Given its increasing saturation as well as environmental and public health concerns, it was relocated to Fyli (in the area of Mount Fyli), in order to serve Western Attica exclusively

3.2. Actual and sample Corine Land Cover (CLC) changes between 1990 and 2000

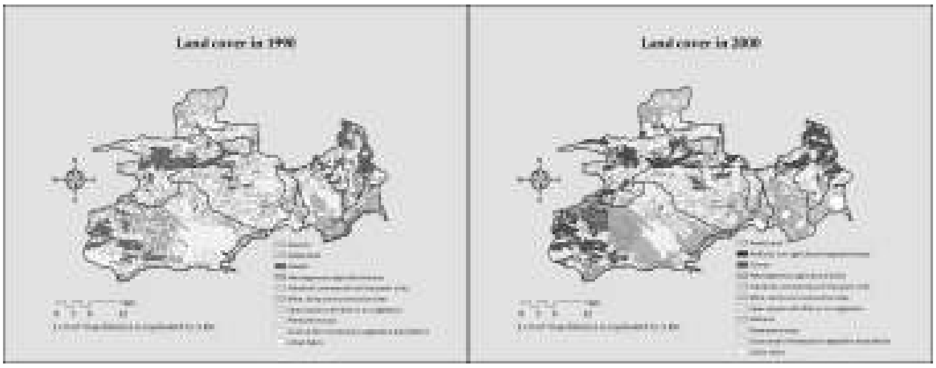
According to EEA's classification, every land use bears a 3-digit land cover code. The first digit refers to the first general class and the last one to the third and more descriptive class. The land uses observed in Western Attica during 1990 and 2000 are summarized in Table 6, codes 111-333.

Level 2 codes provide a first overview of the actual land uses in 1990 and 2000. Actual land uses (Maps 6-7) are then compared to sample changes of artificial, agricultural, forest, and forest and semi-natural areas (Maps 8-11).

There are noticeable indications of deforestation in Thriasio and in the Attica County, especially at the borders of the Capital City. A certain degree of reforestation is observed in Megara (Southern region) and Vilia. The Southern region is also characterized by an increase in agricultural activities. In fact, former arable land has been exploited for agricultural purposes in Megara and New Peramos. Moreover, significant changes may be observed at the borders of the Capital City, namely urbanization of former agricultural areas in Southern Ano Liosia and deforestation in Southern Aspropyrgos. The deforestation of both forest and semi-natural areas as well pure forest areas in Ano Liosia and Fyli are clear indications of the intensive use of the dump site in Ano Liosia between 2007 and 2011 until its final relocation in Fyli. In general, they are indicative of the growing urbanization in Western Attica and Attica.

Table 6: Corine Land Cover (CLC) classes observed in Western Attica in 1990 and 2000

Class 1	Class 2	Class 3	Code
Artificial surfaces	Urban fabric	Continuous urban fabric	111
		Discontinuous urban fabric	112
	Industrial, commercial and transport units	Industrial or commercial units	121
		Road and rail networks and associated land	122
		Port areas	123
		Airports	124
	Mine, dump and construction sites	Mineral extraction sites	131
		Dump sites	132
		Construction sites	133
	Artificial, non-agricultural vegetated areas	Sport and leisure facilities	142
Agricultural Areas	Arable land	Non-irrigated arable land	211
	Permanent crops	Vineyards	221
		Fruit trees and berry plantations	222
		Olive groves	223
	Pastures	Pastures	231
	Heterogeneous agricultural areas	Annual crops associated with permanent crops	241
		Complex cultivation patterns	242
		Land principally occupied by agriculture, with significant areas of natural vegetation	243
		Agro-forestry areas	244
Forest and semi-natural areas	Forests	Broad-leaved forest	311
		Coniferous forest	312
		Mixed forest	313
	Scrub and/or herbaceous vegetation associations	Natural grasslands	321
		Moors and heathland	322
		Sclerophyllous vegetation	323
		Transitional woodland-shrub	324
	Open spaces with little or no vegetation	Bare rocks	332
		Sparsely vegetated areas	333



Maps 6 and 7: CLC2 actual land uses in 1990 and 2000 (left-right)

These results are further confirmed by sample changes of artificial, agricultural, forest, and forest and semi-natural areas (Maps 8-11). Individual land parcel changes have been determined on the basis of the dominant land use within the parcel in 1990 and 2000. Artificial areas as a whole have increased by 10-40% in Thriasio (Aspropyrgos and Elefsina), where most industrial and commercial activities are concentrated, and in those parts of the Attica County, located at the borders of the Capital City (Ano Liosia). The 10-40% increase of artificial areas in Thriasio and in the Attica County has been compensated by a decrease in the corresponding agricultural areas (Maps 8-9). Finally, there are indications of reforestation (pure forest land) by 10-40% (or even >40%) in Western Megara (and Vilia) and deforestation in Thriasio and in the Attica County (Maps 10-11).

Maps 8-9-10 and 11: CLC2 sample land use changes between 1990 and 2000 (top-bottom, left-right)

3.3. Estimation results

The spatial interactions model is estimated in this section. The set of explanatory variables includes land cover changes of artificial (DARTS), agricultural (DAGRA) and forest areas (DFOREST), as well as changes in three census variables (Table 7). Namely, changes in the rate of primary education graduates (DELEM), changes in the employment rate of the economically active population (DEMPLR), and changes in the density of normal dwellings, derived on the basis of the total number of rooms per person (DHMR1). HMR1 is a binary variable, which equals 1 when there is at least 1 room per person and 0 otherwise.

The dependent variable (YFALL) indicates whether a land parcel was deforested or not in 2000 relative to1990. It is a binary variable, which equals 1 in case of deforestation and 0 otherwise. Its values have been determined on the basis of the change in the area of forest and semi-natural areas in 2000 relative to1990. Deforestation corresponds to negative or zero change and reforestation to positive change. The changes in YFALL correspond to deforestation for 103/156 land parcels or 66% of the sample, compared to 97/156 or 62.2% in case of pure forest areas. Table 8 reports the sample correlations of the model variables.

Table 7: Summary statistics of the explanatory variables

Municipality	ELEM			EMPLR			HMR1	
	1991	2001	% Change	1991	2001	% Change	1991	2001
Elefsina	35.8	33.9	–1.9	89.4	93.6	4.2	0	1
Ano Liosia	37.8	35.5	–2.3	88.6	91.9	3.3	0	0
Aspropyrgos	35.1	36.6	1.5	88.1	94.1	6.0	0	0
Vilia	43.3	32.5	–10.8	93.9	93.8	-0.1	0	0
Erythres	34.2	30.0	–4.2	90.3	96.8	6.5	0	1
Zefyri	30.1	35.0	4.9	90.1	90.3	0.2	0	0
Mandra	36.2	29.7	–6.5	90.3	95.9	5.6	0	1
Megara	41.1	34.5	–6.6	93.0	94.6	1.6	0	1
N. Peramos	29.1	24.7	–4.4	90.9	97.1	6.2	0	1
Fyli	35.0	39.9	4.9	92.0	95.2	3.2	1	0
Magoula	39.7	35.3	–4.4	88.7	98.1	9.4	0	1
Oinoi	40.0	35.2	–4.8	98.1	97.2	–0.9	0	1

Table 8: Sample correlations of the model variables

DELEM	DEMPLR	DHMR1	DARTS	DAGRA	DFOREST	YFALL
–0.362***	0.104***	0.220*	–0.272**	–0.094**	0.222*	DELEM
-	0.356***	–0.680***	0.551***	–0.048*	–0.391***	DEMPR
-	-	–0.262**	0.293**	–0.355***	–0.519***	DHMR1
-	-	-	–0.452***	0.180**	0.358***	DARTS
-	-	-	-	–0.360**	–0.271**	DAGRA

Notes: *** means P<0.001; ** means P<0.005; * means P<0.010 (P indicates the rejection probability).

Table 9 reports the parameter estimates of the spatial interactions model on the basis of the fixed point algorithm (FXP2S1) with the standard normal distribution function and one nearest neighbour along with estimates based on alternative estimation methods, for robustness. Namely, estimation in two stages without iterations as if the dependent variable were strictly exogenous (Naïve), two-stage fixed point estimation with none and two nearest neighbours (FXP2S0, FXP2S2), estimation of the generalized linear model with standard normal link function (GLMBP), and estimation of a mixed regressive spatially autoregressive lag model (MRSAL) with continuous dependent variable (Anselin [2]).

3.4. Discussion

Among the reported FXP2S estimates, only FXP2S1 maximizes the pseudo-likelihood function (lnL=–0.231) and yields the largest spatial spillovers. Estimates of the net spatial interactions parameters are reported in Table 10. The estimate of ρ0 is negative everywhere, while that of ρ1 positive, despite the fact that the estimate of ρ, which measures the aggregate spatial spillover, indicates positive action. This implies that equilibrium actions are strategic substitutes for the environment (ESS) and complements for agriculture (ASC), accordingly (Table 1). In other words, the aggregate positive action is in favor of agricultural activities.

Table 9: Model estimates

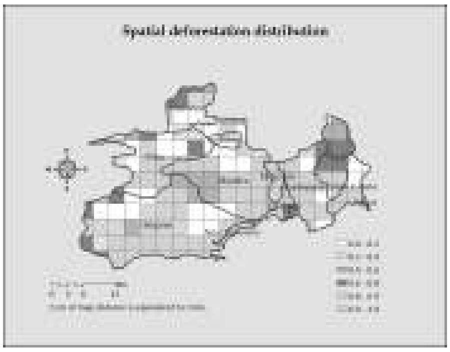
DELEM	MRSAL	Naïve	FXP2S0	FXP2S1	FXP2S2	GLMBP
CST $(-\hat{\rho}_0)$	0.614 (6.28)	1.382 (2.64)	1.357 (36.73)	1.240 (33.50)	1.350 (36.29)	1.263 (2.72)
DELEM	0.009 (0.71)	0.158 (2.36)	0.149 (31.33)	0.161 (31.23)	0.153 (30.01)	0.210 (2.48)
DEMPLR	–0.034 (1.64)	–0.280 (1.95)	–0.229 (27.90)	–0.306 (28.99)	–0.241 (21.72)	–0.413 (2.21)
DHMR1	0.107 (1.22)	1.037 (2.17)	0.953 (27.41)	1.150 (31.54)	0.993 (26.49)	1.562 (2.29)
DARTS	0.018 (4.90)	1.774 (3.36)	1.800 (32.70)	1.799 (33.23)	1.790 (37.71)	1.866 (2.09)
DAGRA	0.014 (5.29)	1.719 (3.40)	1.747 (33.02)	1.743 (33.55)	1.737 (37.92)	1.800 (2.09)
DFOREST	–0.002 (1.12)	–0.007 (1.04)	–0.006 (9.50)	–0.009 (11.99)	–0.007 (12.53)	–0.010 (1.00)
ENDOG $(\hat{\rho})$	0.379 (2.00)	0.679 (0.60)	0.000 (0.00)	1.807 (14.01)	0.138 (1.87)	2.812 (1.28)
lnL	–614.9	–0.233	–0.234	–0.231	–0.235	-

Notes: |t|-values in brackets

FXP2S1 estimates are used in the estimation of the spatial probability distribution of equilibrium strategic actions (Map 12) and the qualification of the type of spatial equilibrium, dictated by the expected strategic behaviour of the network individuals (Figure 1).

Table 10: Model estimates of the net spatial effects

Estimate Spatial effect type	$\hat{\rho} > 0$ Aggregate	$\hat{\rho} - \hat{\rho}_0 = \hat{\rho}_1 > 0$ Agricultural	$\hat{\rho}_0 < 0$ Environmental
MRSAL	0.379	0.989	–0.614
Naïve	0.679	2.061	–1.382
FXP2S0	0.000	1.357	–1.357
FXP2S1	1.807	3.047	–1.240
FXP2S2	0.138	1.488	–1.350
GLMBP	2.812	4.075	–1.263



Map 12: Spatial deforestation equilibrium distribution

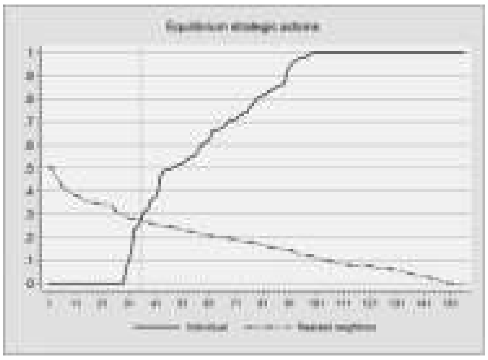


Figure 1: Strategic actions using NFXP2S estimates

The estimated spatial probability distribution is the fixed point of the mapping approximating the joint distribution function. The slope of the individual reaction function (in ascending order) is positive, according to the sign of the aggregate spatial effect ($\hat{\rho}$ = 1.807), and intersects that of nearest neighbours at a single point with value 0.3 < 0.5, that is below indifference. The low value of the spatial equilibrium indicates lack of coordination of strategic actions. In particular, the following behavioural pattern is observed: when the majority of individuals tend to deforest (individuals with values > 0.3), their nearest neighbours tend to choose opposite strategies (nearest neighbours with values < 0.3). According to the spatial deforestation game (Table 1), the estimated behaviour implies lack of coordination of individual environmental actions when their neighbours coordinate their actions in favor of the environment ($\hat{\rho}_0<0$, ESS, (NC,C)), hence deforestation, and on the other hand, lack of coordination of agricultural activities ($\hat{\rho}_1>0$, ASC, (NC,NC)). This confirms actual and sample land use changes between 1990 and 2000 (Figures 3 to 8). In particular, $\hat{\rho}_0<0$ (ESS) is characteristic of deforestation in Thriasio and the Attica County, while $\hat{\rho}_1>0$ (ASC) of agricultural activities in Megara and New Peramos (Southern region), and to a lesser extent in Thriasio and the Attica County.

4. Concluding Remarks

The present paper is an environmental application with focus on deforestation in the Greek region of Western Attica. It relies on methods of spatial statistics and econometrics to determine the degree of coordination of strategic clearing of forest and semi-natural areas by individuals active in Western Attica between 1990 and 2000, on the basis of land use changes. Empirical results are summarized as follows:

- Individual equilibrium strategies are net strategic substitutes for the environment and complements for agriculture, whereas the aggregate spatial spillover is positive and equal to 1.807, implying that expected individual actions produce a positive spillover in favor of deforestation.
- Equilibrium strategic actions are environmental substitutes in Thriasio and the Attica County, where most industrial activities are concentrated, and agricultural complements in the Megara and New Peramos (Southern region), which supply the Capital City with agricultural products.
- The spatial distribution of equilibrium deforestation actions is characteristic in Thriasio, the Attica County, and the municipalities of Megara (Southern region) and Vilia.
- The degree of coordination of individual expected actions is relatively low, implying a relative absence of appropriate central planning on the part of the local government.

Moreover, the proposed estimator is conceptually simple and methodologically credible. It is applicable to both small-sized social networks, with given dependence structure and large random samples.

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