ON THE STRENGTHENING OF ASSOCIATION BETWEEN ARTIFICIAL LIGHT-AT-NIGHT INTENSITIES AND PRIMARY, SECONDARY, TERTIARY AND QUATERNARY INDUSTRIES CONCENTRATIONS IN EUROPE

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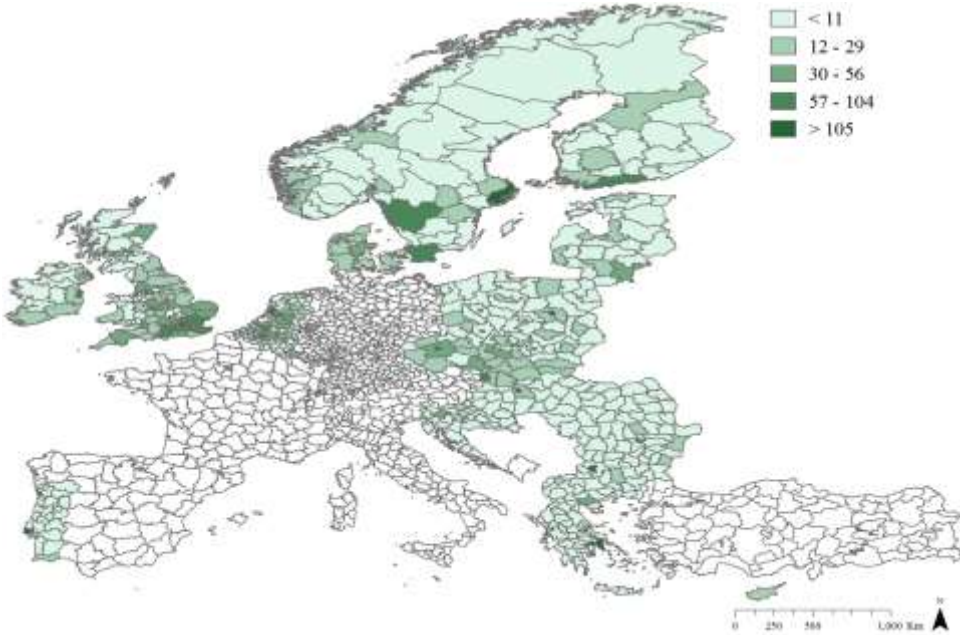
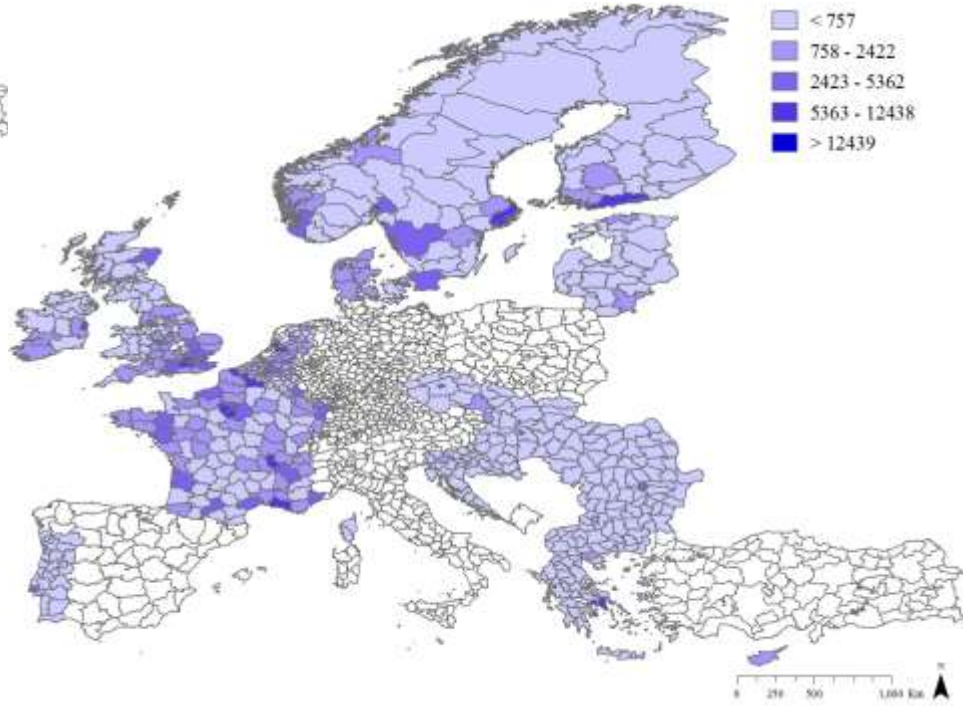
Background

- **Quaternary industries** (QIs) are widely considered as the main **driving force** behind modern economic growth
- The **identification** of regional concentrations of QIs thus becomes an important thrust of regional studies and policy design
- However, **relatively little information is presently available** on geographic concentrations of QIs

Data availability for QI concentrations in the EU

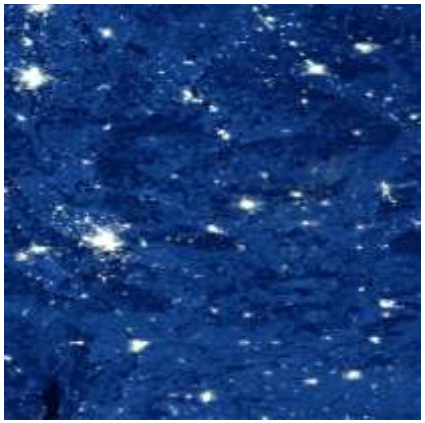




Distribution of professional activities across European NUTS3 regions with available data: **Employment density**, persons per km^2 (**green**) and **Gross value added**, million euro (**purple**)

ALAN as an economic activity marker

ALAN, reaching satellite sensors, is likely to **differ by intensity**, **depending on its source**. It thus can become a **marker** for different types of economic activities, helping to distinguish between specific economic activities on the ground.

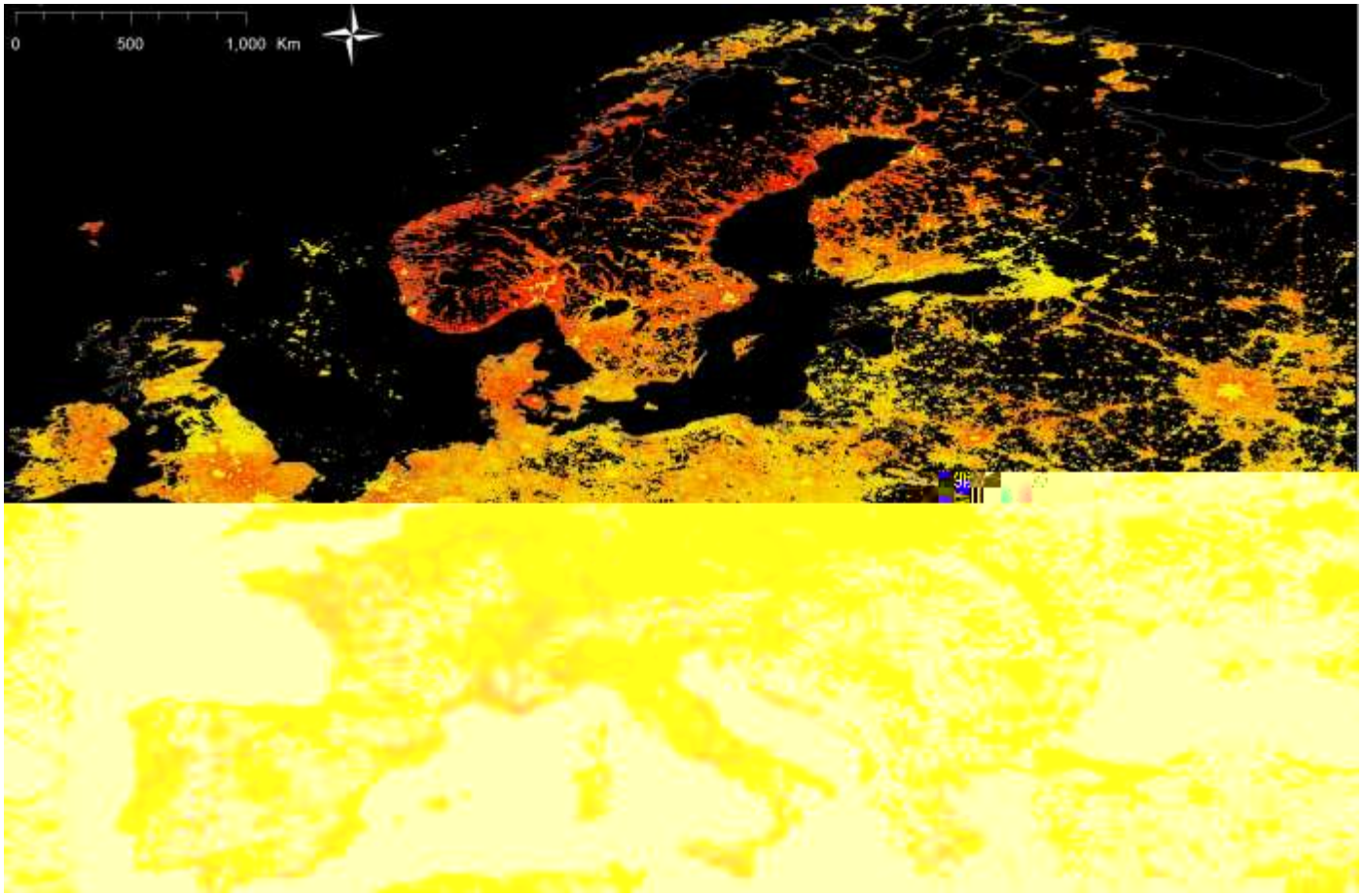


a)

b)

Economic activities and light emitted by them at night: mainly agricultural region in **Northern Ukraine** (left) and industrial concentration, entertainment and commerce around **London and Paris** (right) *Source:* Defense Meteorological Satellite Program (DMSP, 2014).

ALAN levels detected by US DMSP satellites in 2010



Source: Mapped using US DMSP (NOAA, 2014) data; *Note*: Areas emitting highest ALAN levels are marked red, less lit areas are marked in orange and yellow; areas with no stable lights appear in black.

Previous studies

- **ALAN** vs. **health issues** (Kloog et al., 2007, 2009, 2010)
- **ALAN** in **demographic analysis** (Elvidge et al., 1997; Imhoff et al., 1997; Sutton et al., 2001; Anderson et al., 2010)
- **ALAN** and **economic performance** of areas (Doll et al., 2000; Sutton et al., 2007; Henderson et al., 2009; Ghosh et al., 2010; Kulkarni et al., 2011; Mellander et al., 2013)
- **ALAN** as **economic concentrations identification tool - *generalized*** (Ebener et al, 2005; Doll et al., 2006; Bhandary & Roychowdhury, 2011) and ***industry-specific*** (Rybnikova & Portnov, 2014; 2015)

Study objective

The study aims to investigate whether ALAN intensities can be used for identification of QIs on-ground concentrations, measured in terms of employment density (ED; persons per km^2) or gross value added (GVA; Euro Mill.).

Study hypotheses

QIs are expected to be positively associated with ALAN levels due to:

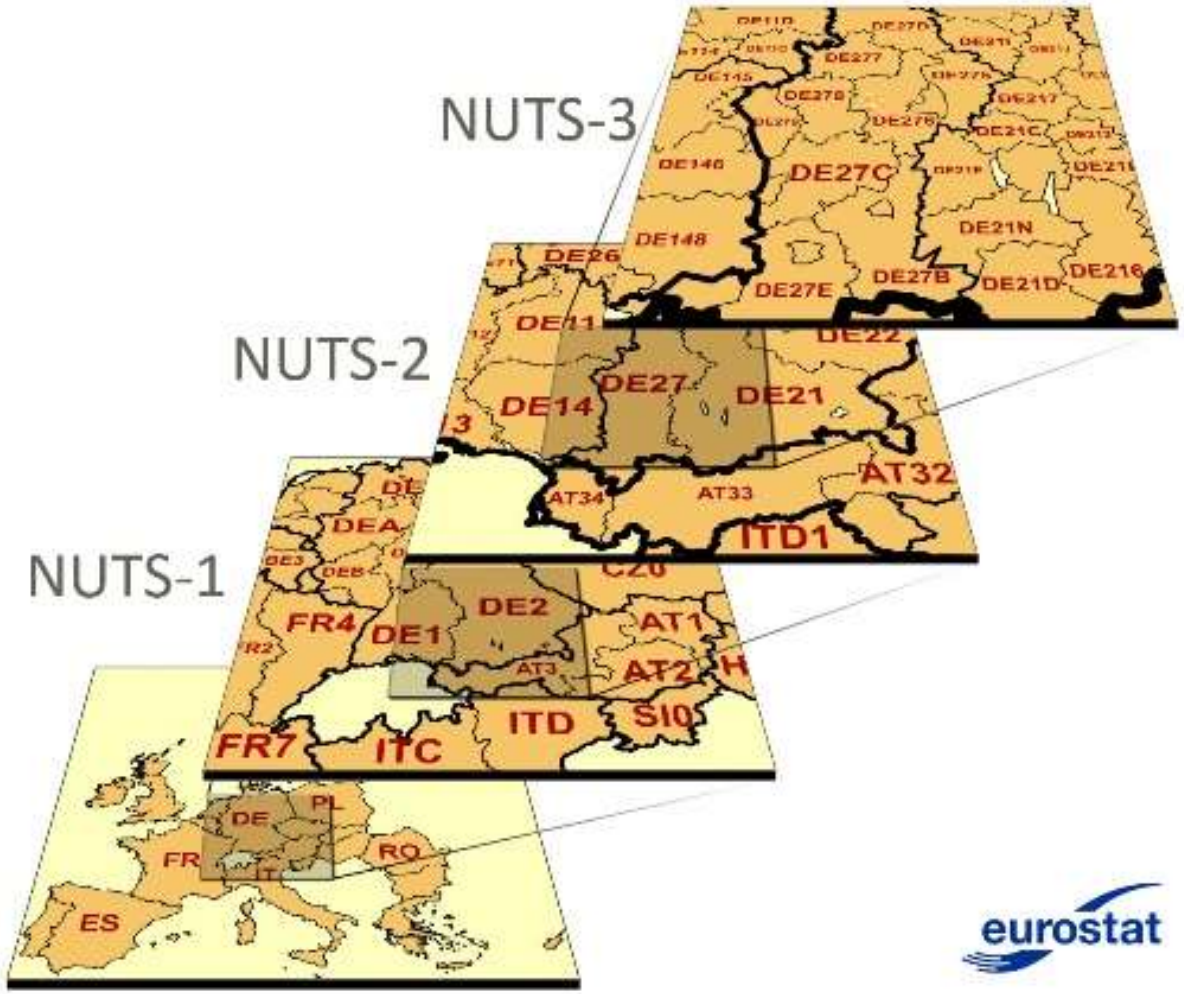
high concentration of workforce;

flexible working regime, extended in night hours;

clustering of service-oriented and entertainment facilities around.

This association is expected to be stronger compared with the association between ALAN and either primary, secondary or tertiary industries.

Study area: European NUTS3 regions



Types of Economic activities under analysis

QIs: professional, scientific and technical activities, administrative and support service activities;

TIs: wholesale and retail trade, repair of motor vehicles and motorcycles, accommodation and food service activities;

SIs: manufacturing;

PIs: mining and quarrying.

Data sources

- ✓the U.S. Defense Meteorological Satellite Program (DMSP, 2014)
- ✓the Eurostat Portal (EP, 2013)
- ✓the ESRI ArcGIS ™ database (ESRI, 2013)

Research model: OLS regression

$$MC_{(QI,TI,SI,PI)} = b_0 + b_1 * ALAN + \mathbf{b} * \mathbf{PP} + \boldsymbol{\varepsilon}$$

$MC_{(QI,TI,SI,PI)}$ = measure of concentration, estimated as either ED (persons *per* km^2) or GVA (million euro) metrics for quaternary, tertiary, secondary and primary sectors;

b_0, b_1 and vector **b** are regression coefficients;

ALAN = average ALAN intensities emitted from NUTS3 regions (dimensionless units);

PP = vector of **potential predictors**:
per capita GDP (euro),
population density (persons *per* km^2),
average July and January temperatures (°C),
elevation above the sea level (estimated for NUTS3 centroids in meters),
distances to the seashore, rail, nearest major populations center and to the nearest river (km);

ε = random error term

Additional research models

To address the issue of endogeneity (i.e., a loop of causality between ALAN as predictor and EA concentration as dependent variable), the **2-Stage Least Squares (2 –SLS)** regressions were used:

$$MC_{(QI,TI,SI,PI)} = b_0 + b_1 * \widehat{ALAN} + \mathbf{b} * \mathbf{PP} + \boldsymbol{\varepsilon},$$

$$\widehat{ALAN} = b_{01} + \mathbf{b_1} * \mathbf{PP} + \boldsymbol{\varepsilon_1},$$

$\widehat{ALAN}$ = potentially endogenous variable, estimated via vector of instrumental predictors **PP.**

Spatial dependency modelling

To consider for spatial correlation, **spatial error (SE)** models were tested:

$$MC_{(QI,TI,SI,PI)} = b_0 + b_1 * ALAN + \mathbf{b} * \mathbf{PP} + \boldsymbol{\varepsilon}_n,$$

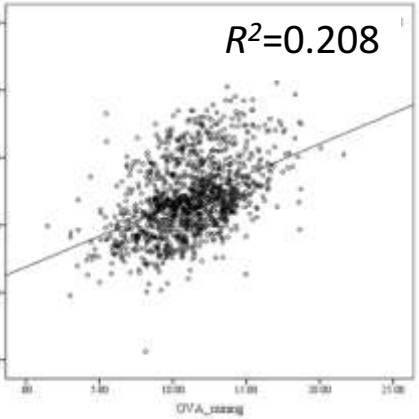
$$\varepsilon_n = \lambda_n \cdot W \cdot \xi + \varsigma,$$

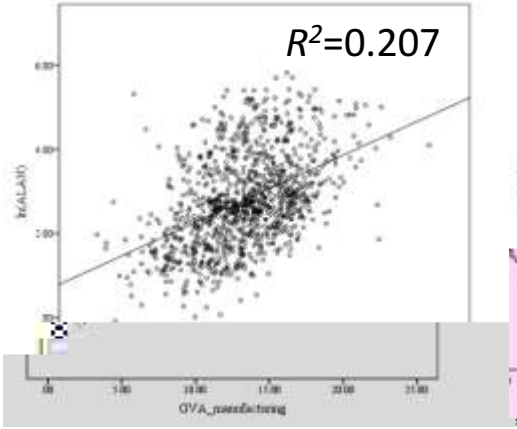
λ = spatial error coefficient;

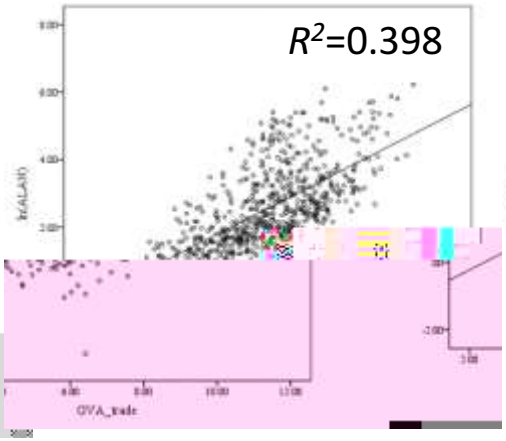
ξ = the vector of error terms, spatially weighted using the weights matrix (***W***);

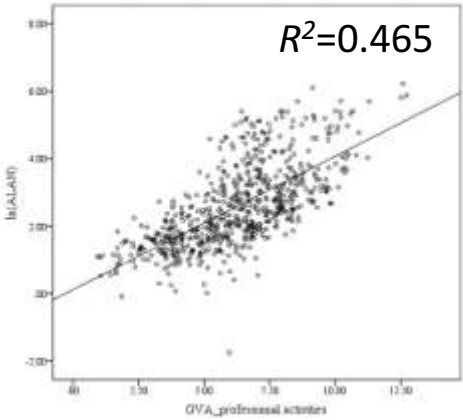
ζ = vector of uncorrelated error terms.

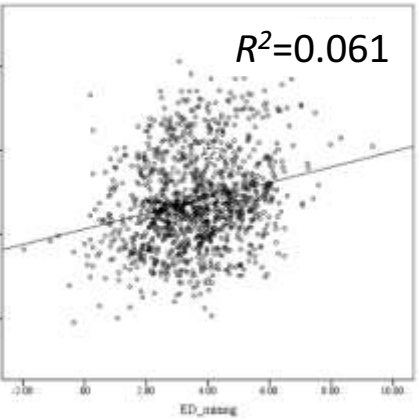
Results: General Trends

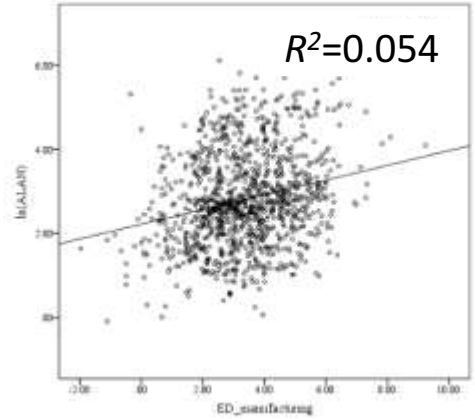


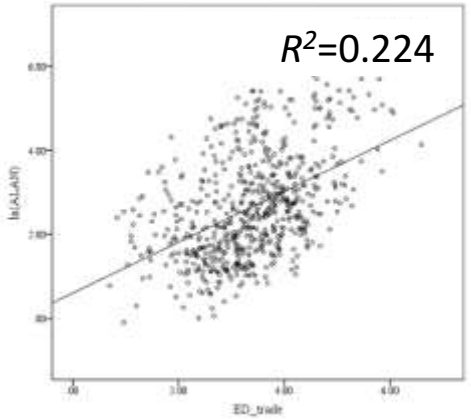


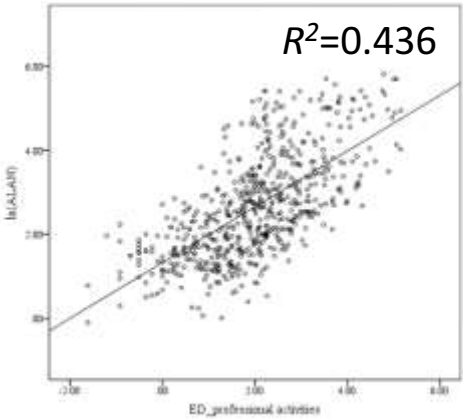












Primary industries

Secondary industries

Tertiary industries

Quaternary industries

Results: OLS regressions

Variable	Primary Industry		Secondary Industry		Tertiary Industry		Quaternary Industry	
	B[a]	t[b]	B[a]	t[b]	B[a]	t[b]	B[a]	t[b]
(Constant)	-4.004	(-3.776)***	-5.256	(-3.835)***	-4.631	(-8.814)***	-8.658	(-8.763)***
Ln(ALAN)	0.946	(10.915)***	1.211	(9.856)***	0.387	(11.557)***	0.679	(14.608)***
Ln(GDPpc) (euro)	1.269	(10.969)***	1.314	(8.720)***	1.087	(18.962)***	1.413	(15.945)***
Population density (persons per km^2)	-1.57E-04	(-2.056)**	-0.001	(-4.392)***	–	–	–	–
January temperature (°C)	-0.168	(-6.909)***	-0.179	(-5.701)***	–	–	–	–
D_rivers (km)	0.001	(4.415)***	0.002	(6.286)***	–	–	–	–
Elevation (m)	0.001	(2.788)***	0.001	(1.993)**	–	–	–	–
D_seashore (km)	–	–	0.004	(4.248)***	0.001	(5.583)***	0.001	(4.634)***
D_mcities (km)	–	–	-0.005	(-5.909)***	–	–	–	–
D_rail (km)	–	–	–	–	-0.001	(-4.861)***	–	–
July temperature (°C)	–	–	–	–	–	–	-0.035	(-2.560)**
N of obs.	1198		1035		637		640	
R^2	0.213		0.364		0.618		0.679	
Adjusted R^2	0.212		0.359		0.616		0.677	
F	(91.717)***		(73.513)***		(255.561)***		(336.083)***	

Results: 2-SLS regression

Variable	Primary Industry		Secondary Industry		Tertiary Industry		Quaternary Industry	
	B[a]	t[b]	B[a]	t[b]	B[a]	t[b]	B[a]	t[b]
(Constant)	-5.201	(-3.470)***	-5.746	(-2.877)***	-5.067	(-8.436)***	-9.134	(-8.286)***
$Ln(\widehat{ALAN})$[e]	0.530	(1.708)*	1.306	(2.982)***	0.326	(6.288)***	0.631	(8.392)***
Ln(GDPpc) (euro)	1.507	(6.965)***	1.327	(4.457)***	1.143	(16.410)***	1.459	(13.798)***
Population density (persons per km^2)	4.34E-05	(0.253)	0.000	(-1.815)*	–	–	–	–
January temperature (°C)	-0.142	(-5.585)***	-0.108	(-3.369)***	–	–	–	–
D_rivers (km)	0.001	(2.657)***	0.002	(4.981)***	–	–	–	–
Elevation (m)	0.001	(2.053)**	0.001	(1.358)	–	–	–	–
D_seashore (km)	–	–	0.005	(5.319)***	0.002	(5.537)***	0.001	(5.092)***
D_mcities (km)	–	–	-0.006	(-7.683)***	–	–	–	–
D_rail (km)	–	–	–	–	-0.001	(-4.666)***	–	–
July temperature (°C)	–	–	–	–	–	–	-0.032	(-2.104)**
N of obs.	1198		1035		637		640	
R^2	0.249		0.310		0.564		0.614	
Adjusted R^2	0.246		0.305		0.562		0.612	
F	(65.973)***		(57.660)***		(204.766)***		(252.694)***	
SEE[c]	2.379		2.634		0.921		1.318	

Notes: *Indicates a 0.1 two-tailed significance level; **Indicates a 0.05 significance level; ***Indicates a 0.01 significance level. [a] Unstandardized regression coefficient; [b] *t*-statistic; [c] Standard error of the estimate.

Results: SE regressions

Variable	Primary Industry		Secondary Industry		Tertiary Industry		Quaternary Industry	
	B[a]	z[b]	B[a]	z[b]	B[a]	z[b]	B[a]	z[b]
(Constant)	-9.908	(-6.213)***	-10.500	(-5.501)***	-5.223	(-7.522)***	-11.281	(-8.772)***
Ln(ALAN)	0.887	(8.983)***	1.277	(9.691)***	0.371	(9.526)***	0.657	(12.049)***
Ln(GDPpc) (euro)	1.855	(10.907)***	1.761	(8.749)***	1.145	(15.239)***	1.611	(13.888)***
Population density (persons per km^2)	-3.63E-04	(-4.641)***	-0.001	(-6.788)***	–	–	–	–
January temperature (°C)	-0.198	(-5.184)***	-0.208	(-4.091)***	–	–	–	–
D_rivers (km)	0.001	(1.540)	0.002	(3.731)***	–	–	–	–
Elevation (m)	0.001	(1.362)	4.90E-04	(0.955)	–	–	–	–
D_seashore (km)	–	–	0.006	(3.660)***	0.001	(3.768)***	4.37E-04	(3.774)***
D_mcities (km)	–	–	-0.004	(-3.877)***	–	–	–	–
D_rail (km)	–	–	–	–	-0.001	(-3.165)***	–	–
July temperature (°C)	–	–	–	–	–	–	-0.008	(-0.402)
λ	0.585	(20.485)***	0.541	(16.819)***	0.406	(9.010)***	0.466	(10.997)***
N of obs.	1198		1035		637		640	
R^2	0.485		0.507		0.674		0.739	
SEE[c]	1.966		2.216		0.794		1.080	

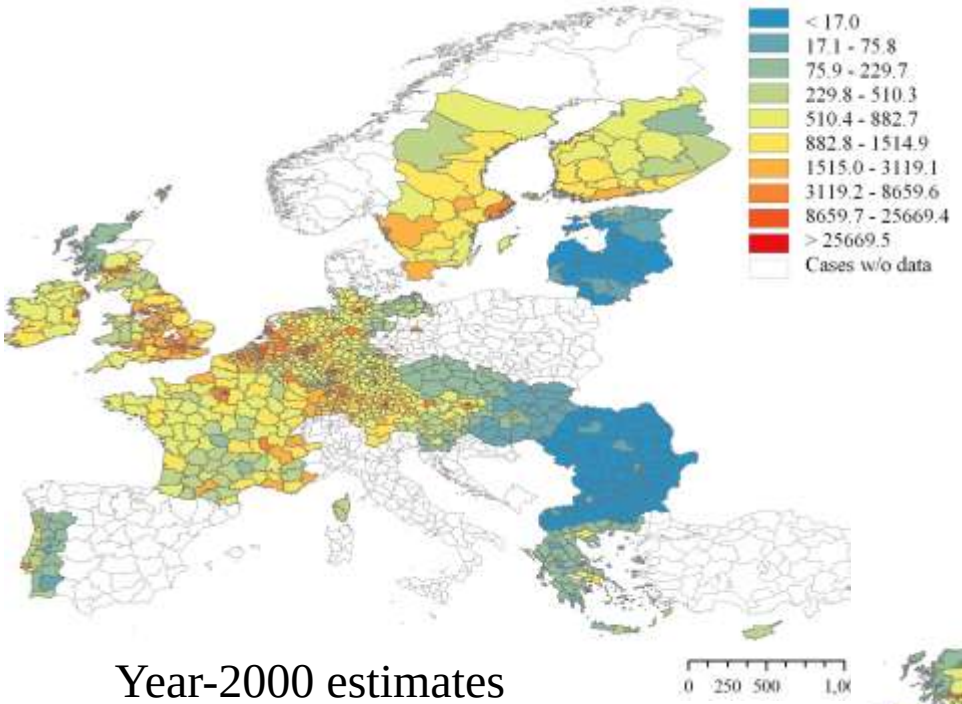
Notes: *Indicates a 0.1 two-tailed significance level; **Indicates a 0.05 significance level; ***Indicates a 0.01 significance level. [a]Unstandardized regression coefficient; [b] z-statistic; [c] Standard error of the estimate.

Results: *F*-test of R^2-change

Prediction OLS model	R^2 change attributed to ALAN inclusion in addition to other predictors	
	R^2-change	*F*-statistic
Primary Industry	0.068	(119.134)***
Secondary Industry	0.060	(97.142)***
Tertiary Industry	0.084	(140.768)***
Quaternary Industry	0.108	(213.390)***

Note: *** Indicates a 0.001 two-tailed significance level.

Estimates for Qis concentrations



Year-2000 estimates

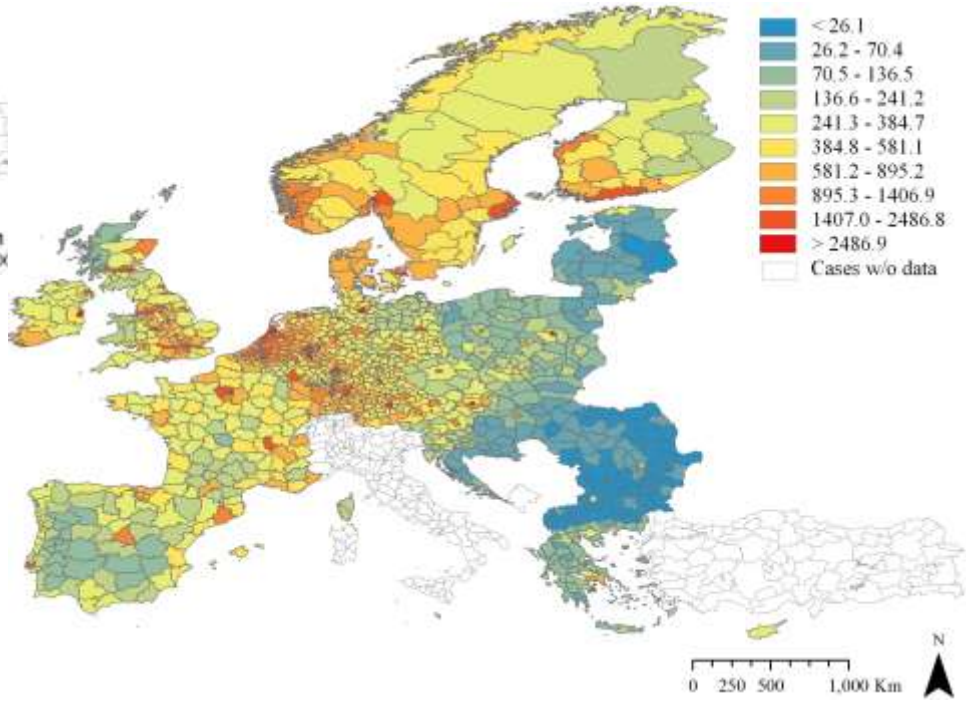
(**973 regions,** GVA, in million euro)

Note: The estimates are based on Model 8

Year-2010 estimates

(**1232 regions,** GVA, in million euro)

Note: The estimates are based on Model 8



Conclusions

- ALAN intensities, together with other explanatory variables, such as GDP*pc*, population density, and geographic attributes of NUTS3 regions, helped to explain **up to 74% of QIs' regional variation**
- **ALAN-QIs association appeared to be stronger** compared with either ALAN-TIs, ALAN-SIs or ALAN-PIs associations (t=14.608 vs. $|t|$<11.557)
- For the **year-2010**, our models helped to **restore missing information** on on-ground concentrations of QIs in **1232** NUTS3 European regions, that is, up to about 85% of their total number

Update: Data availability on GVA (mln euro)

(a) Primary sector, 2010 year

(b) Primary sector, 2013 year

(c) Primary sector, 2015 year

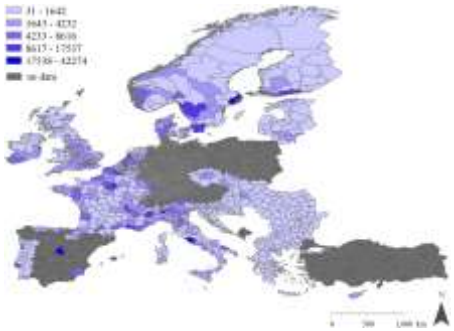
(d) Secondary sector, 2010 year

(e) Secondary sector, 2013 year

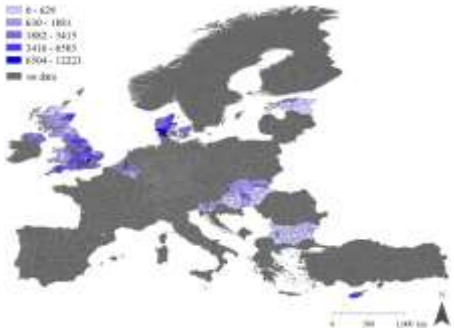
(f) Secondary sector, 2015 year

Update: Data availability on GVA (mln euro)

(g) Tertiary sector, 2010 year



(h) Tertiary sector, 2013 year



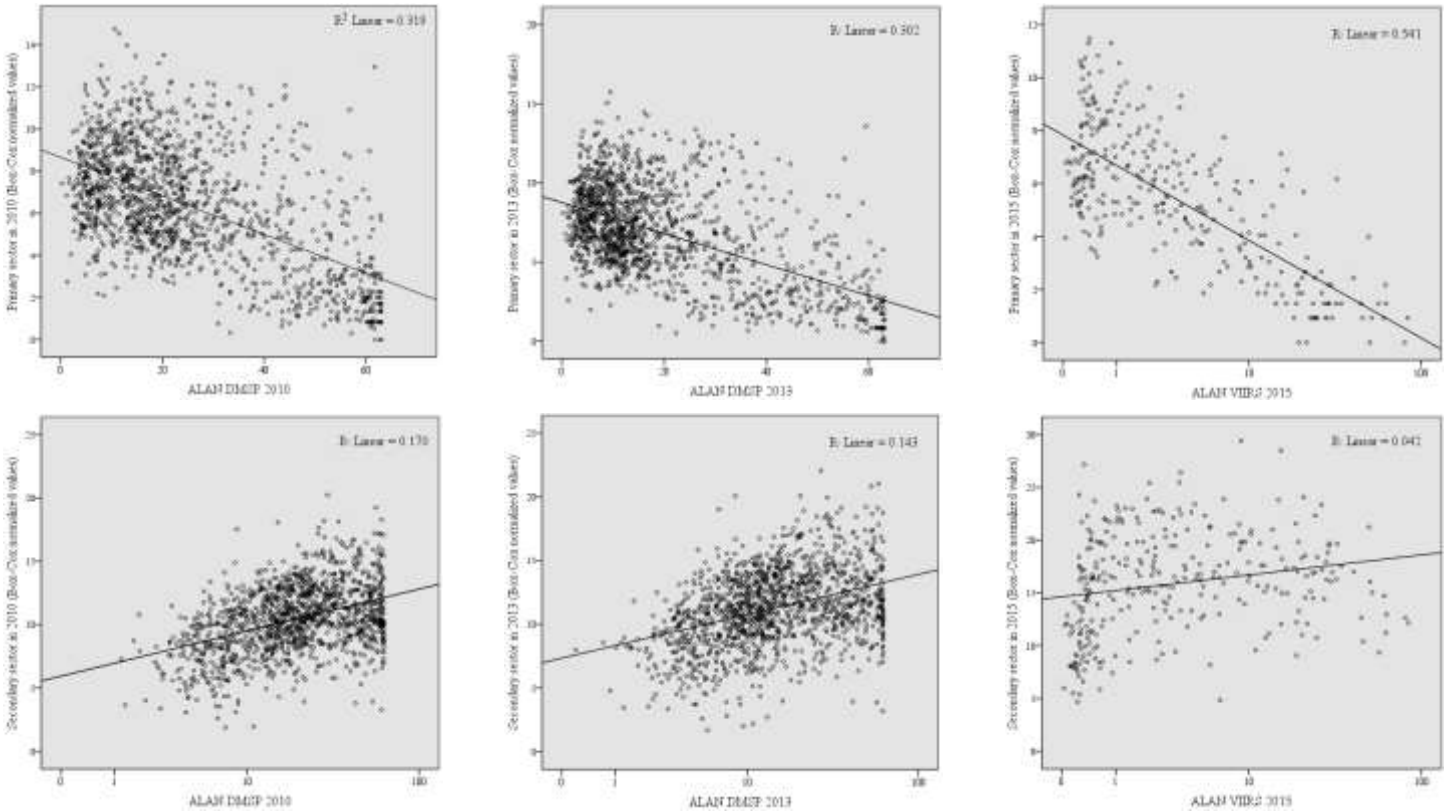
(i) Tertiary sector, 2015 year

(j) Quaternary sector, 2010 year

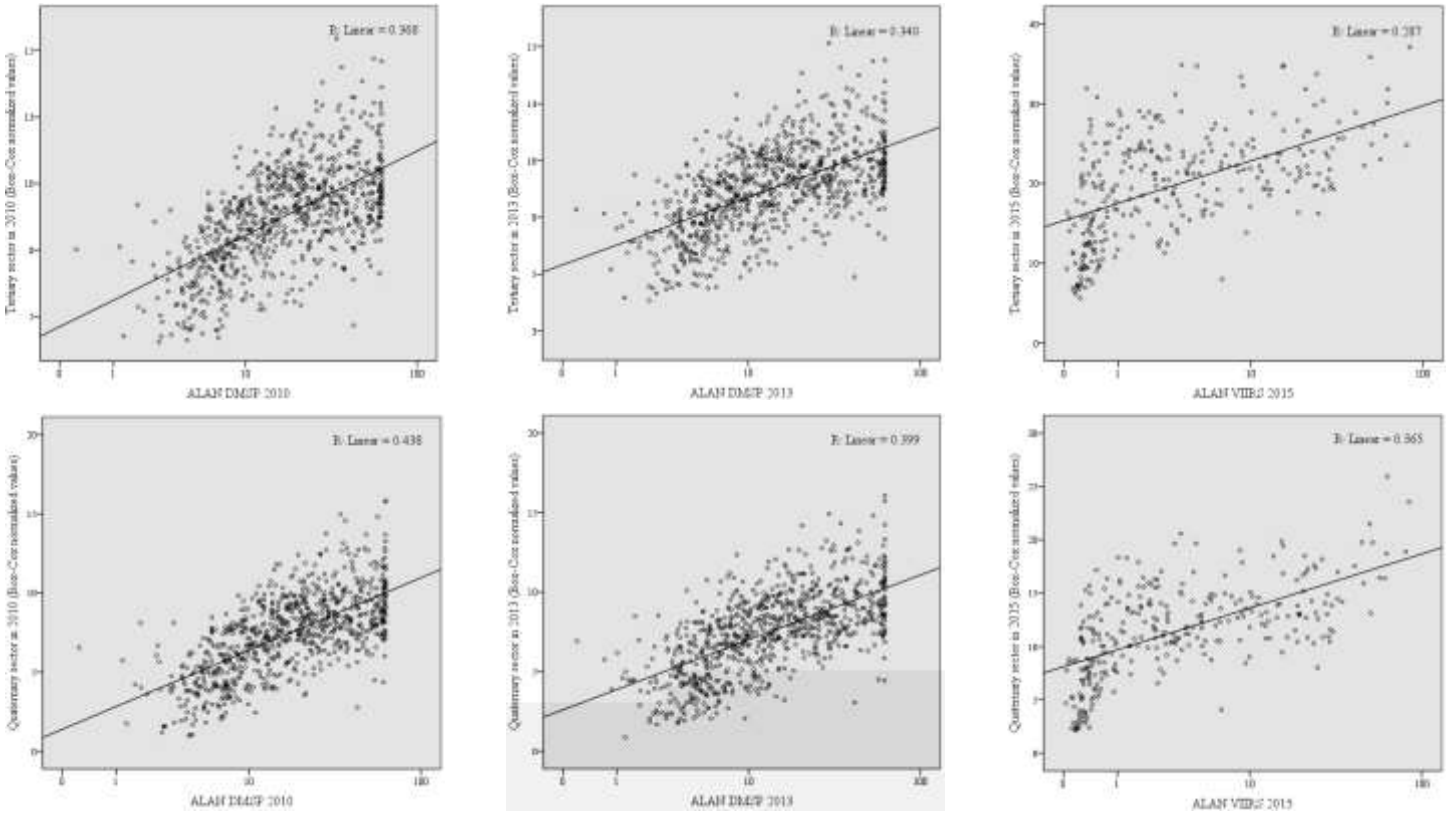
(k) Quaternary sector, 2013 year

(l) Quaternary sector, 2015 year

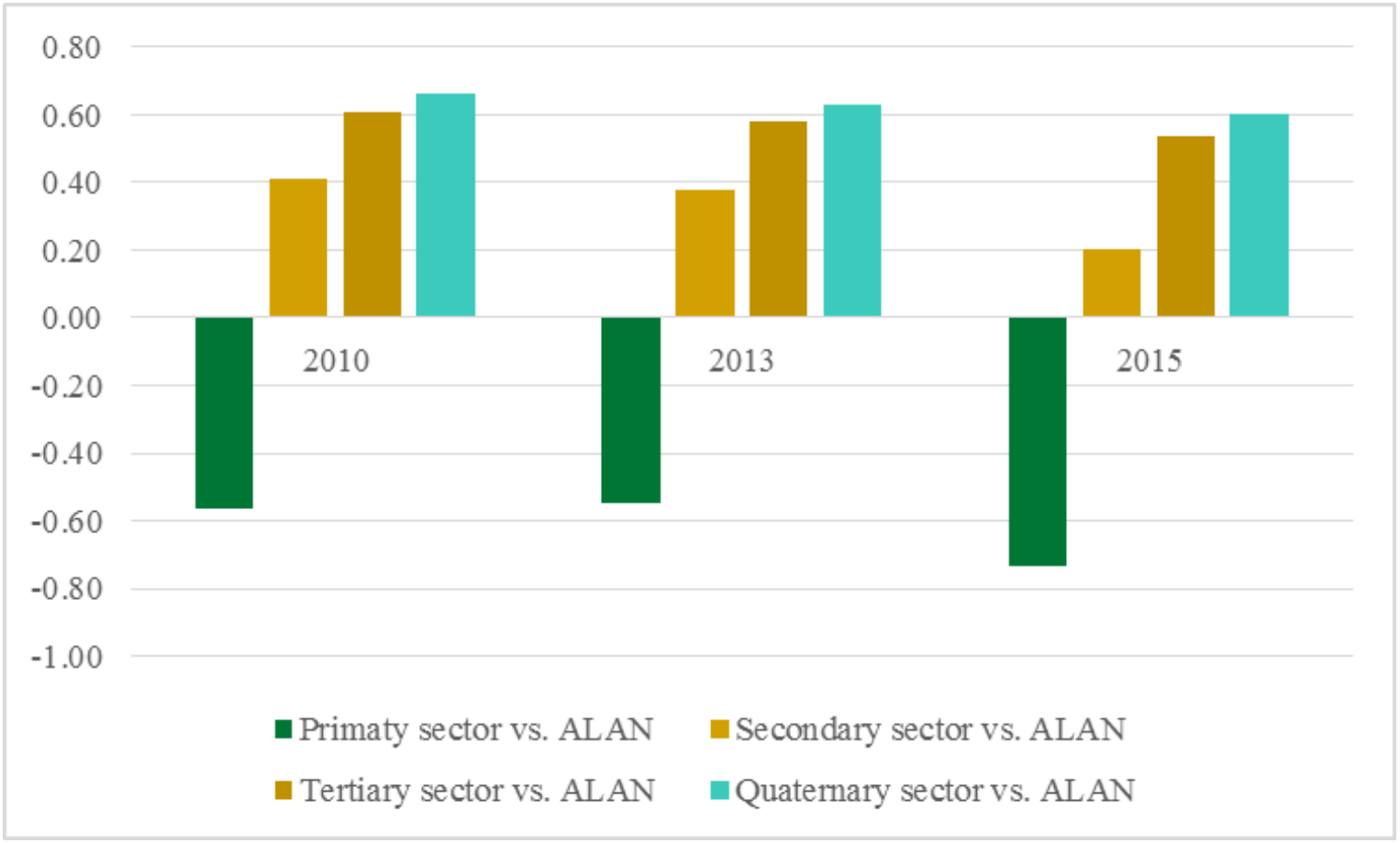
Update: Association between ALAN and economic sectors



Update: Association between ALAN and economic sectors



Update: Association between ALAN and economic sectors (Pearson correlation)



Thank you!

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