ROBUST

Deliverable 2.3

Socio-economic analysis of the urban-rural continuum of the Frankfurt / Rhine-Main region

An in-depth exploration at small spatial scale

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Abstract

The aim of the study was to elaborate and pilot a method for assessing how linkages between urban and rural activities affect socio-economic development. For that purpose, an in-depth exploration of socio-economic variables at micro-spatial scale (neighbourhood) was carried out to monitor the evolution of functional linkages around the private sector and employment and how both influence sustainable welfare in the German case study region. Connections between share of commercial estate, level of purchasing power, demographic structure, unemployment rate and other variables are made visible with the microm database.

Note on the collaborative context

The terms of reference of this study were deduced from the project proposal (as part of the Description of the Action) and agreed with the Regionalverband Frankfurt/Rhein-Main after exchanging on the methodological approach and the related databases on 7 December 2017. The main reason for sub-contracting had been the exclusive access of the contractor to the RWI-Geo-Grid data. The study was elaborated by Rüdiger Budde (RWI) in close cooperation with Rolf Bergs and Moneim Issa (both PRAC).

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List of abbreviations

AIC	Akaike Information Criterion
FDZ	Forschungsdatenzentrum (Research data center)
GDP	Gross Domestic Product
KDE	Kernel Density Estimation
NUTS	Nomenclature des unités territoriales statistiques
VIIRS	Visible Infrared Imaging Radiometer Suite

Summary

The purpose of the study at hand was to explore the information content of small scale grid and commuter data for a socio-economic analysis of urban-rural relations. The findings help to precisely detect socio-economic patterns at small spatial scale (one square kilometre grid) under consideration of environmental limits of local resource consumption. The analysis builds on the statistical classification of functional space determined by population density (eight urban, peri-urban and rural classes of space based on EU defined threshold margins). The statistical approach applied was kernel density estimation. For the purpose of its reliability the classification results were further compared with the variation of radiance from night satellite data. By the subsequent use of a spatial econometric model (Spatial Durbin Model) estimates show the association and spatial cause & effect relations for several variables at neighbourhood scale (one square kilometre resolution). To deepen the inferential analysis, the spatial classification was linked to a commuter flow analysis by clustering municipalities along their functional variation. In this analysis the spatial links of the local labour market and the economic interaction between the different functional classes of area can be shown. An attempt to conceptualize the target variable "disposable income" in a context of sustainability was less successful with the data available. The use of local spatial impedance data directly linked to with disposable income turned out to be technically unfeasible and thus not meaningful. More useful has been the exploration of systematic relationships between microm grid data and night satellite images. Here, population density correlates stronger with light emission only in urban areas. Commercial density correlates significantly with light emission across all areal classes regarded, thus well defining light emission as a variable showing economic activity.

In how far can rural-urban synergies and dependencies be shown?

- Classification of functional space can be obtained by kernel density estimation;
- Spatial synergies/dependencies can be proved for the variables purchasing power, unemployment rate, Commercial density, migrant, car class preferences and credit worthiness;
- Rural-urban synergies can be shown by commuter balance analysis along spatial classes;
- The study shows evident cause-effects relations under consideration of spatial autoregressive effects for the dependent variable and for all covariates.

1 Introductory remarks

1.1 Background and aim of the study

Economic growth is regarded as one of the basic indicators in an economy. Its nature illustrates the extent to which an economy can generate wealth. If a similar concept of measurement is to be applied to sub-regions, it will only be successful to a limited extent, since these sub-regions assume certain functional tasks in spatial interaction, depending on the task they are assigned or the resources they are endowed with. Constellations of different tasks are conceivable that challenge a community with conflicting problems and move it to the focus of spatial planning through coordination or cooperation. The concept of a spatial-functional division of tasks is based on the idea that the different subspaces of an overall space are differently suitable for one or more functions. Each subspace should therefore be developed in the best possible way according to its suitability. In this context it has to be considered that the development in cities and agglomerations and the increasing mobility of the population have considerable effects on the economy and the environment and promote further developments.

In order to take the theoretically postulated needs into account, empirical approaches are attempted to structure spaces via their settlement density and thereby take into account their functional division of tasks. This has a long historical tradition. This way, J.F. von Thünen had developed a first economic-geographical location theory (Thünen 1826), while the European Union proposes a spatial classification according to population densities for intra-European spatial comparisons (Degree of urbanisation classification – 2011; revision 2018). They suggest a system of 3 categories: the rural area with less than 300 inhabitants per km^2, the peri-urban area with more than 300 and up to 1500 inhabitants/km^2 and the metropolitan areas with more than 1500 inhabitants/km^2. This demarcation is initially taken as a basis. It seems somewhat too rough for detailed analyses, so that the individual groups can be considered more differentiated if necessary.

If spatial planning wishes to adopt such an approach, it is faced on the one hand with the task of supporting the development of traditional space within its political boundaries. On the other hand and in order to quantify regional development dynamics, it is quite usual to consider functional commuter zones (Klemmer 1975) or regions delimited by planning (Boustedt 1953, ARL 1984). In such a view, administrative territorial units are combined to form a superordinate entity. Since official socio-economic data are only available at a rather high aggregation level their spread at the neighbourhood level is concealed and policy is essentially based on a too coarse data foundation. The change from averages within administrative units to small-scale network data now allows a much more precise description and analysis of larger spatial units and the creation of homogeneous areas. Standardized areas (e.g. 1 km^2) facilitate the execution of structural analyses below the level of administrative units. From the viewpoint of exploring the functional rural-urban nexus at small spatial scale, such grid data appear highly attractive and thus deserve prominent consideration in respective research.

By using socio-economic grid data in addition to commuter data at municipality level, the model region Frankfurt / Rhine Main is explored with a view to,

- how a functional space perspective for the study area and its administrative units can be derived on the basis of a small-scale population distribution.
- how the area and how the population as a whole and the demographic structure change over time,
- what kind of influence certain spatial structures have on economic growth

- and how mobility affects spatial exchange among urban, peri-urban and rural parts of the region.

The study is structured into introductory remarks on the region and the data sources (chapters 1.2-1.5), a descriptive statistical part comprising a statistical classification of urban, peri-urban and rural areas of the study region and an analysis of association between small-scale grid data with radiance (chapters 2 and 3). Chapters 5 and 6 represent the core analytical part of the study; they comprise the spatial econometric analysis of important socio-economic patterns along the rural-urban continuum and the interaction on the labour market among the different areal classes.

1.2 The Frankfurt / Rhine-Main Region

As a metropolitan region, the Rhine-Main Region is of particular importance not only for Germany but also for Europe as a whole. The Ministerial Conference for Spatial Planning (MKRO) defines metropolitan regions as large conurbations of outstanding national and international importance, with driving forces for society, the economy, including social and cultural development attributed to them, which continue to have an effect on the surrounding countryside (see http://www.deutsche-metropolregionen.org/ueber-ikm/hintergrund/). For the investigation at hand, the delimitation of the research area will differ from the Ministerial Conference for Regional Planning (official designation: Frankfurt/Rhine-Main conurbation in accordance with § 2 (1) of the Law on the Metropolitan Region Frankfurt/Rhine-Main of 8 March 2011). The study region regarded is rather the territory of the Regional Authority Frankfurt/Rhine-Main.

1.3 Required Data Sources and Their Availability

As stressed above, the researchers suggest that small-scale data in the form of one square kilometre grids should be chosen as the basis for the analysis. With the help of such an analysis not only small-scale structures within administrative units can be identified, but such structures can be also adequately assigned across administrative boundaries. This approach, however, does not exclude the possibility that information from a large spatial viewpoint, such as the municipality level, can be used in the analysis.

The RWI-GEO-GRID provided by the FDZ Ruhr am RWI, comprises data which can overcome the above-mentioned shortcomings. The dataset is based on a grid which is uniformly defined by 1×1 kilometre raster cells. The grid level is defined according to the EU directive standardized European projection system INSPIRE (Infrastructure for Spatial Information in Europe). INSPIRE ensures that different data on the same projection can be merged to each other. 2 In total, there are around 362,000 1-km2 grid cells for Germany. Residential or commercial property are located in more than 218,550 grid cells, and for those socio-economic data are provided in the RWI-GEO-GRID dataset (DOI: 10.7807/microm:einwohner:V4) (Budde 2014).

The data are regularly collected by the commercial micro- and geo-marketing provider Micromarketing-Systeme und Consult GmbH (microm). Its main fields of business are target marketing, the analysis of local market conditions, and multi-channel marketing. To this end, microm uses more than one billion individual data points for the aggregation of their dataset. These stem from various data sources. The data points are available for all 40.9 million households in Germany, while the final data product contains information on approximately 20 million buildings (microm 2017).

1.4 Spatial Data and their implicit properties

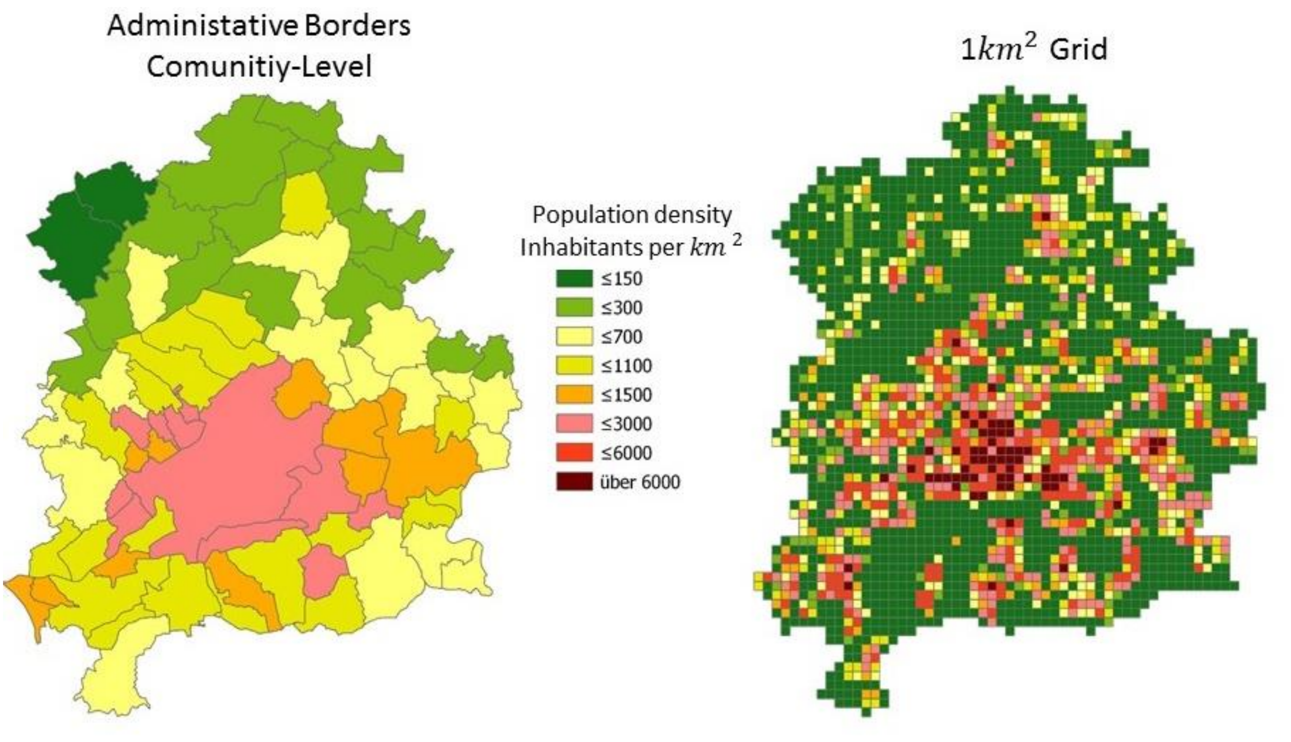
The population figures provided by official statistics differ slightly from those of microm. In 2015, for example, a number of 2,319,023 persons is reported by the Hessian State Statistical Office, while an aggregation across all grids of the regional association amounts to just 2,257,159 inhabitants. The minor difference of -

2.6% is to be explained by different survey methods. But for this study, the absolute size of the population in the region as a whole is less important than its spatial distribution.

Spatial data have different characteristics such as size, location or extent and cannot always be directly compared with regard to a content characteristic such as population number or population density without further consideration. Thus, the 75 municipalities in the Frankfurt/Rhine-Main area show significant differences in size. While the municipality with the largest population has almost 750,000 inhabitants (Frankfurt), the municipalities with no more than 3500 inhabitants have the smallest population. A similarly divergent pattern of expansion can be observed (the largest municipality extend to approximately 250 km^2 /the smallest one just 4.5 km^2).

A change from administrative units to small-scale network data allows a more precise description of larger spatial units and the creation of homogeneous areas. If the areas under consideration are standardized (e.g. to 1 km^2), the individual sub-areas differ only in their geographical location and the measured frequency of the examined characteristic. At this level, up to 2500 grids of the same size will be investigated, whereby the number of inhabitants per square can vary from a maximum of 20,000 to a minimum of less than 5 inhabitants. The different approach can be well illustrated in Figure 1: the raster map contains much more information than the map at the level of municipalities and cities.

Figure 1: Population Density, 2015, on different spatial Levels



Own calculations based on data from microm and Detatis)

In order to consider as much spatial information as possible, raster data in the form of grids in 1km^2 will form the basis for the following analysis. With the help of such an analysis, not only small-scale structures within administrative units can be identified, but such structures can be also adequately assigned across administrative boundaries. However, this approach does not exclude the possibility that information from a broad spatial perspective, such as the community level, can be used in the analysis.

1.5 Public data sources in the internet

Over the years the content of general statistical data has been harmonized. Most national, the European and international statistical authorities also offer comparable data across national borders, so that researchers can access binding data canons. In order to be able to address small-scale spatial research, researchers are increasingly resorting to geo data. Since these contain spatial information as well as statistical characteristics, this type of data is so far only offered to a limited extent by statistical offices. As this type of data can be generated from different sources, such as satellite images, surveys or geo-coordination, different official and commercial providers generate such data. These different development paths have resulted in a substantial supply of small-scale spatial data offered by different providers. Further to that there is the advantage that data are often provided open and free of charge. Due to the different strands of development the data supply on the Internet is somewhat confusing, so that the search for data sources can be burdensome. For this reason, Table 1 lists some web pages for initial information. It has to be stated that the EU's INSPIRE initiative, which has led to a harmonization of data stocks, has proved particularly helpful in this context.

Table 1: Data sources for small scaled spatial data

Content	Link
Eurostat: Population Grids on 1km2 Basis, 2006 and 2001	https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/geostat
European Environment Agency: Table text Reference grid for each European Country. (INSPIRE-BASIS)	https://www.eea.europa.eu/data-and-maps/data/eea-reference-grids-2
Copernicus Data Pan-European Land-use: Corinne Land Covers, High Resolution Layers, European Settlement Area, partly from 1990 onwards	https://land.copernicus.eu/pan-european
Copernicus Data Local Data: Urban Atlas, Riparian Zones, Natura 2000 (N2K)	https://land.copernicus.eu/local
European Data Portal: Search bot for geo data, sources by nations	https://www.europeandataportal.eu/data/en/organization?sort=&q=&page=2
European Commission: Inspire Geo-Portal	http://inspire-geoportal.ec.europa.eu/
ESRI- Open Data: Free geo-Data (partly grid-data) GISGeography: Collection of links concerning geo-data data (partly grid-data)	http://hub.arcgis.com/pages/open-data https://gisgeography.com/best-free-gis-data-sources-raster-vector/
EU Open Data Portal: Access to European Union open data	https://data.europa.eu/euodp/data/dataset?tags=raster+data
Exemplary selection of national sources:	
Dutch geo data sets Finnish geo data sets (partly grid-data)	https://www.pdok.nl/datasets https://research.csc.fi/open-gis-data

Internet search by the author.

2 Classification and delimitation of the examination area

The raster map in Figure 1 clearly shows that rural grids (less than 300 inhabitants per square kilometre) often lie within a short spatial distance of each other and also form area-wide units. The metropolis-oriented grids (with at least 1500 inhabitants per square kilometre) tend to form hotspots, which are distributed in different ways across the Frankfurt/Rhine-Main region. Clearly visible, Frankfurt as a major city stands out from the other spaces. The spatial distribution of the grids, which are neither urban nor rural, lies naturally between the first two categories, but diffuses more across the surface than the other two categories.

By categorising the data by setting thresholds, the impression can arise that large differences between the population and population density can be observed in the neighbourhoods between the individual grids. However, on the one hand, this is partly due to the cartographic representation. On the other hand, it can be assumed that values from neighbour grids influence each other in terms of spatial contiguity/proximity effects. It is therefore appropriate to adjust the basic data by using statistical methods. One such method is the kernel density estimation.

2.1 Methodical approach

Kernel density estimation (KDE) is a nonparametric method for estimating the probability density function of a random variable. In addition to classical classification and dimension reduction methods such as cluster and factor analysis, it can be used to describe social spaces. It is used to solve a basic data smoothing problem where conclusions are drawn about the distribution of the population from a finite data sample. The effects refer to the intensity or density of the spatial point pattern and can be simplified by defining the number of events per area, like a heatmap.

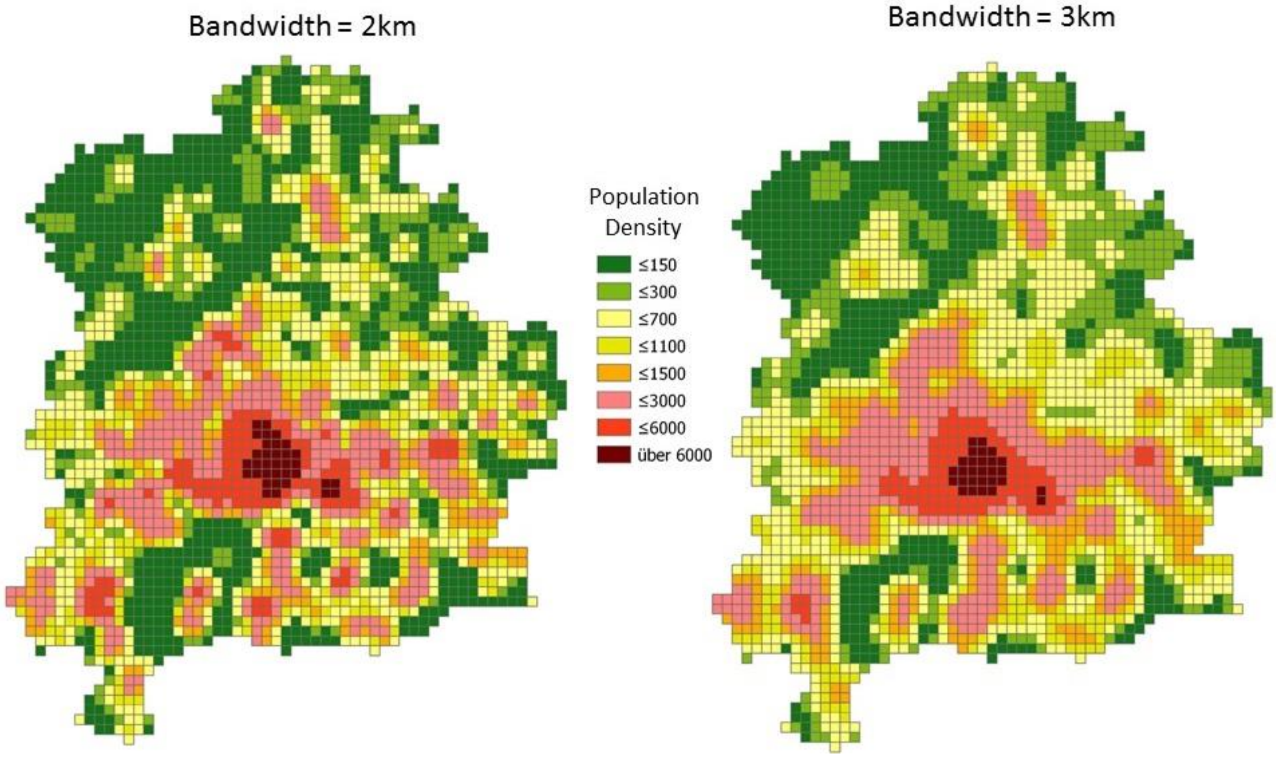
Various functions are available for the kernels. The normal distribution is used relatively frequently in practice, which has the advantage that it can cover a value range of $\pm\infty$ and thus covers all points in the study area. In addition, so-called "quartic" and "triangle" nuclei are also used. In contrast to the dispersion or bandwidth of the kernel, the choice of kernel as such has only a minor influence on the result (cf. Wand and Jones 1995). In this evaluation a Gaussian or normally distributed kernel estimator is used.

The dispersion or bandwidth of the spatial distribution has a direct major influence on the kernel density estimate. For the determination of the bandwidth there are no clear statistical specifications, it is often determined more or less subjectively, guided by considerations of adequacy.

2.2 Results of kernel density estimation

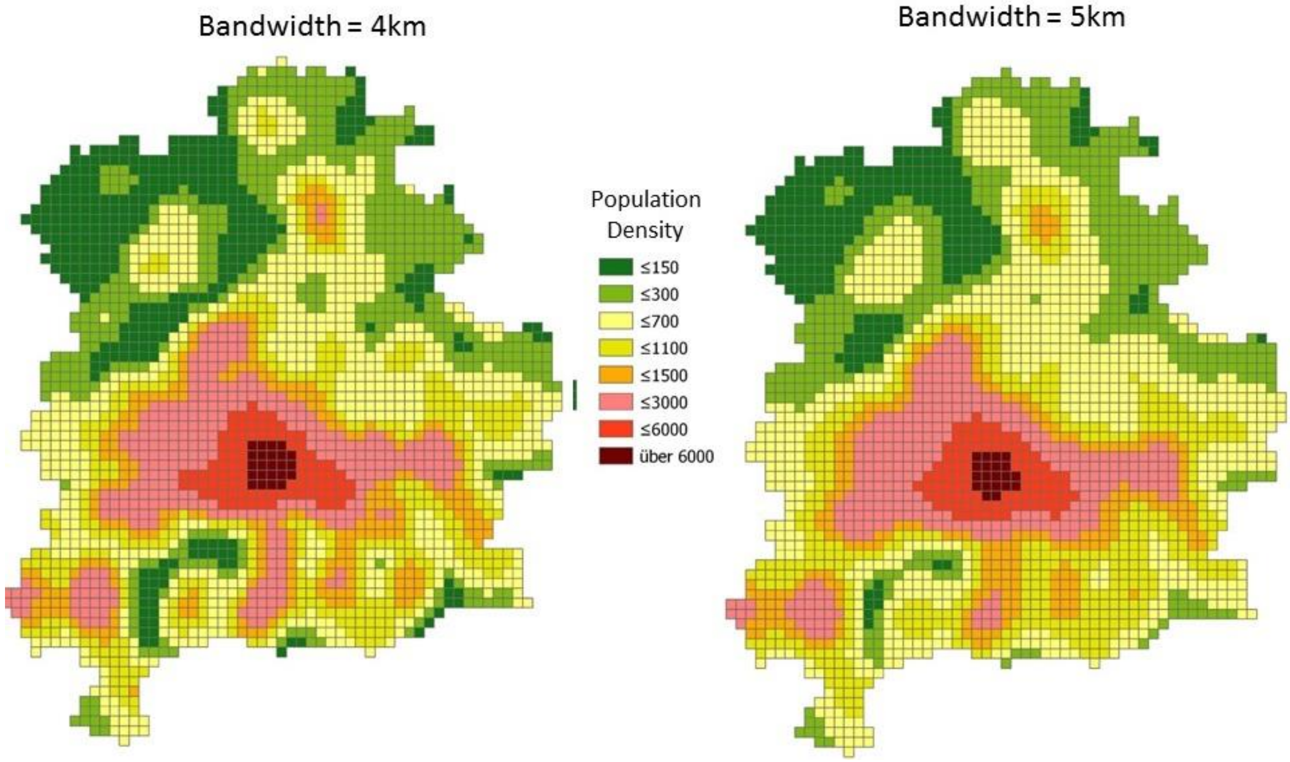
The method of KDE is applied on the population distribution of the year 2015 with different bandwidths. The bandwidth varies in an interval of two to five kilometres, with a stepwise increase of one km in each case. This increase was chosen so that additional assumptions on characteristics of distribution within a grid are not needed. As Figures 2 and 3 show, a larger bandwidth leads to a larger smoothing of the original spatial distribution.

Figure 2: Population density, 2015, bandwidths 2 and 3 km



Own calculations based on data from microm.

Figure 3: Population density, 2015, bandwidths 4 and 5 km



Own calculations based on data from microm.

If grids of an estimate that are spatially adjacent and belonging to the same class of population size are combined, the numbers of newly created spaces give an indication of the extent to which the applied KDE reduces the information. Table 2 provides an overview of the extent to which the estimations flattens the distribution of the population at raster level in 2015. For example, according to an estimate of the 2 km range, 710 of the approx. 800 spatial units are left over. As the bandwidth increases, the number of areas decreases to almost 85 (bandwidth = 5km). If the reduction of spatial units are compared, the absolute amount of the reduction is the biggest with the KDE bandwidth of 3 kilometres. This can be interpreted as an indication that, among all the considered estimations, those with a range of 3 kilometres provide an optimal result. To test the reliance of the classification results they were linked to a further analysis of variation of radiance from night satellite images. Therefore this this result is used for the investigations further below.

Table 2: Number of spatial units in different Kernel density estimates

Original Distribution		**Bandwidth**			
		2	**3**	**4**	**5**
Population density	**Number of spatial units**	**Number of spatial units**			
Up to 150	54	52	29	19	8
150 up to 300	121	165	87	39	20
300 up to 700	163	159	78	36	18
700 up to 1100	116	144	90	42	13
1100 up to 1500	107	110	84	41	19
1500 up to 3000	155	59	17	6	4
3000 up to 6000	101	19	3	1	1
6000 and more	23	2	2	1	1
total	840	710	390	185	84
absolute reduction of spatial units		-130	-320	-205	-101

Own calculations based on data from microm.

3 Light data by satellite images

In addition to the analysis of delimiting spatial structures presented here, there are other methods of achieving comparable spatial boundaries. For example, Bergs and Issa (2018) submitted a proposal to structure the Frankfurt/Rhine-Main region by means of light data recorded by satellites. This result will be compared with the spatial-structural considerations carried out here so far.

Table 3: Characteristics of the light data according to spatial structures

			2012			2017		
Category	Code	Population density, estimated by a KDE	mean	standard deviation	coefficient of variation	mean	standard deviation	coefficient of variation
Rural	1	<=150	2,9828	9,8259	3,2942	3,4892	9,7659	2,7989
	2	150 < x <=300	3,8422	6,6088	1,7201	4,1870	6,3267	1,5110
Peri Urban	3	300 < x<= 700	4,2896	6,5055	1,5166	4,7373	6,6604	1,4060
	4	700 < x<=1100	4,0229	3,1889	0,7927	4,6255	4,0377	0,8729
	5	1100 < x<=1500	5,7156	5,2234	0,9139	6,1602	5,2288	0,8488
Metropolitan Areas	6	1500 < x<=3000	7,7075	5,7460	0,7455	8,3528	6,2004	0,7423
	7	3000 < x<=6000	12,2360	12,0035	0,9810	14,2142	15,3896	1,0827
	8	>6000	22,3013	16,7751	0,7522	26,9335	20,0100	0,7433

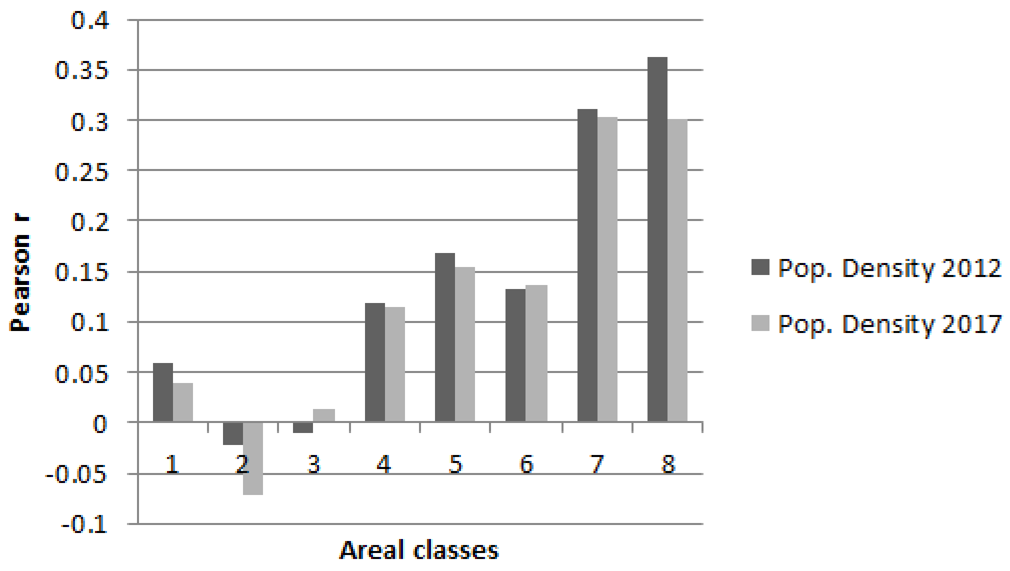
Own calculations based on data from microm.

The derived light data are grouped by the regional results of the population Analysis of the grid data 2015. The coefficient of variation shows a slight increase in light scattering with decreasing luminous intensity. However, in the context of such an analysis method this is still within a tolerable range[1]. Therefore the above result of the kernel density estimation is used for the investigations further below.

Further to that, night satellite data contain socio-economic and environmental information that could be a valuable asset for research on regions where such socio-economic grid data are not available. The respective association can be shown by correlation analyses between radiance and grid data and should complement the earlier study of Bergs and Issa (2018) that was also elaborated within the ROBUST project. For the study at hand an analysis of the strength of correlation between (i) population density and (ii) commercial unit density with respect to light emission (VIIRS) at one square kilometre level was executed to explore patterns of association for the different areal classes. Figures 4 and 5 illustrate those patterns.

[1] Possibly a correction of the data from light-intensive buildings could still improve the result.

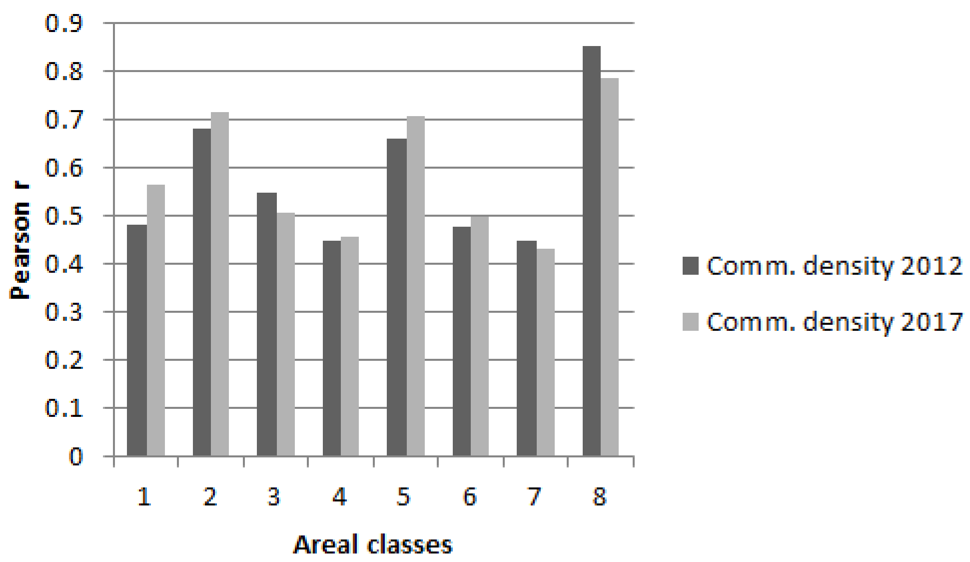
Figure 4: Correlation between radiance and population density



For population density, Pearson r is moderate, but increases with areal classes. As regards the comparison between 2005 and 2015 there is some minor variation that might stem from the correlation analysis with data from different years. In case of the earlier estimate the difference is seven years, hence only the later estimate 2015/2017 appears meaningful.

As regards commercial unit density the association among the different areal classes appears different as compared with that of population density.

Figure 5: Correlation between radiance and commercial unit density



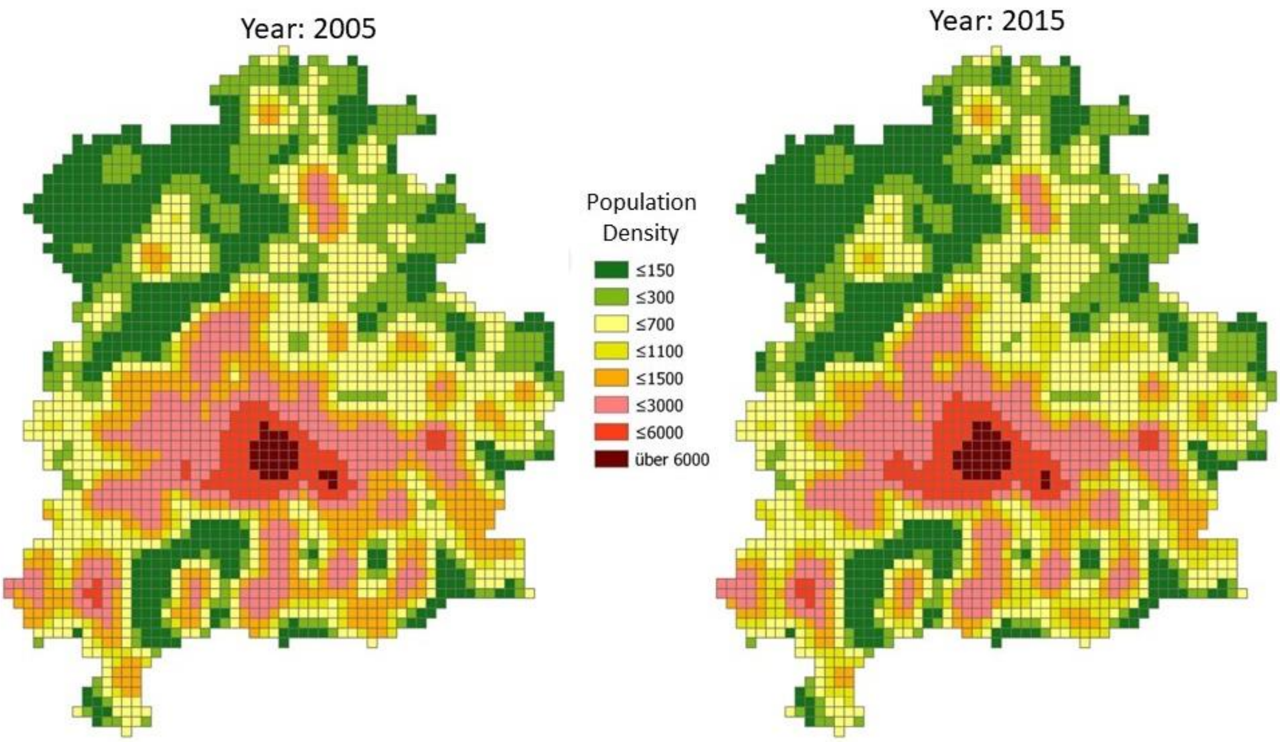
It shows a substantially stronger correlation than for population density but less variation of Pearson r and with maxima in areal class 8. Hence, there is some reason to assume a systematic relevance for radiance as a proxy variable for commercial density. This also supports respective findings of several studies exploring night satellite images for estimating economic activity across space. Testing radiance as a proxy variable in regions without access to such grid data is thus worth to consider.

4 Statistical results based on kernel density analysis

4.1 Change over time

In the following analysis with a ten year time horizon the change of functional space determined by population density is closer looked at. microm grid data show a rise in population in the Frankfurt / Rhine-Main Region by almost 3% from 2005 to 2015 so that the number of inhabitants amounted to 2.57 million. This rise is hardly reflects in the results of the kernel density estimations (range=3km) between 2005 and 2015 (Figure 5 and Table 3). Nearly 94% of the grids have the same population size class in both 2005 and 2015, while in 2005 only 1.5% of the grids belonged to a higher population class in 2005 and 4.8% to a lower population class. While population gains are more evenly distributed across nearly all population classes, losses are more pronounced in the less populated classes.

Figure 6: Cartographical presentation of the results of the kernel densities analysis between 2005 and 2015.



Own calculations based on data from microm.

Table 4: Comparison of population classes between 2005 and 2015

Population density	Absolute number of grids that belonged to …… category of population density in 2005 compared to 2015		
	a higher	the same	a less
Up to 150	6	1414	
150 up to 300	9	111	24
300 up to 700	8	190	17
700 up to 1100	3	130	15
1100 up to 1500	7	93	19
1500 up to 3000	3	201	21
3000 up to 6000	3	170	13
6000 and more		49	13
Total	39	2358	122

Own calculations based on data from microm.

4.2 Changes within the spatial distributions of the population

If one first considers the extent to which the population in the individual areas is roughly divided into rural, peripheral and metropolitan areas, it is noticeable that in a comparison of the years 2005 and 2015 the population in rural areas has remained constant, while in the peri-urban areas a population decline of 0,7 percentage points in favour of metropolitan areas can be observed (table 4 and table 5).

In addition to these changes of population in the major functional areas, it can be stated that within the peri-urban areas, for parts of its population the living in the less populated areas (300 up to 1100 inhabitants per square kilometre) seems less desirable in 2015 than in 2005. Their percentage declines while a rise can be observed in the more dense parts of the peri-urban areas. In the urban areas especially the upper density class of population (6000 people per square kilometre) is gaining in population shares, while the less populated areas can almost gain their shares.

Table 5: Changes within the spatial distributions of the population between 2005 and 2015

	Inhabitants per km²	2005	2015	Inhabitants per km²	2005	2015
Rural Areas	below 300	2,4	2,4	below 150	1,0	1,0
				150 up to 300	1,3	1,4
Peri-Urban Areas	300t up to 1500	17,8	17,1	300 up to 700	4,7	4,5
				700 up to 1100	6,4	5,8
				1100 up to 1500	6,8	6,8
Metropolitan Areas	above 1500	79,8	80.5	1500 up to 3000	22,2	21,9
				3000 up to 6000	36,0	35,2
				above 6000	21,6	23,5
Total		100,0	100,0		100,0	100,0

Own calculations based on data from microm.

This development becomes directly visible if one considers the growth rate of the population in the individual spatial categories. Referring to the RWI-GEO-GRID database (microm), it can be observed that between 2005 and 2015 the population will grow by 3% in the region as a whole. This growth rate can also be observed in the rural regions, while in the peri-urban areas the growth is 1 percentage point below the overall region. In metropolitan areas, the population is growing at a slightly above-average rate. It is particularly noticeable that within the regions the more densely populated areas can retain significantly more of the population than the sparsely populated ones. Population losses can be observed between 2005 and 2015 in the sub regions with a population density of less than 150 inhabitants per square kilometre, 300 to less than 700 and 700 to less than 1100 inhabitants per square kilometre.

Table 6: Growth rates between 2015 and 2005 in %

	Inhabitants per km^2	in%	Inhabitants per km^2	In%
Rural Areas	below 300	3,1	below 150	-1,7
			150 up to 300	6,7
Peri-Urban Areas	300 up to 1500	-1,0	300 up to 700	-0,7
			700 up to 1100	-6,8
			1100 up to 1500	4,2
Metropolitan Areas	above 1500	3,9	1500 up to 3000	1,3
			3000 up to 6000	0,5
			above 6000	12,2
Frankfurt/Rhine-Main region		3,0		

Own calculations based on data from microm.

4.3 Demographic trend and its changes

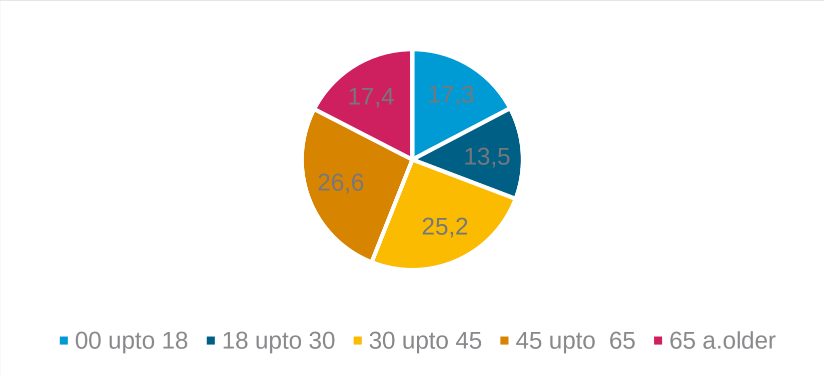
In order to investigate the demographic development in the metropolitan region, the population has been divided into the following age groups.

Table 7: Specification of the demographic structure

Age	Specification
00 up to 18	children and adolescents in training
18 up to 30	young adults with a start in working life
30 up to 45	individuals in the middle of working life
45 up to 65	individuals at the end of working life
65 and older	no longer employed persons

Based on the specification in Table 7 the analysis shows that the age structure is fairly homogeneous for the entire region (Figure 7).

Figure 7: Demographic distribution of the Frankfurt/Rhine-Main region, in 2015



Own calculations based on data from microm.

This homogenous distribution is also visible within the various spatial classes. The minor spread observed in the spatial structures (Table 8) could be possibly explained by the social preferences of the respective age structures such that young adults may prefer the urban environment because of the educational and cultural offerings. In addition, the public transport infrastructure in these areas is particularly well-developed while those who are not gainfully employed tend to avoid the densely populated areas in cities.

Table 8: Demographic structured of the Frankfurt/Rhine-Main region, in 2015

		Age in years				
		0 up to 18	18 up to 30	30 up to 45	45 up to 60	65 and older
Rural Areas	below 150	18,5	12,0	24,2	27,3	18,0
	150 up to 300	18,7	12,1	24,1	27,5	17,5
	below 300 (aggregated)	18,6	12,1	24,1	27,4	17,7
Peri-Urban Areas	300 up to 700	18,6	11,8	24,4	27,2	17,9
	700 up to 1100	18,7	12,3	24,4	27,3	17,3
	1100 up to 1500	18,3	12,1	24,3	26,9	18,4
	300 up to 1500 (aggregated)	18,5	12,1	24,4	27,1	17,9
Metropolitan Areas	1500 up to 3000	18,2	12,6	24,4	27,0	17,8
	3000 up to 6000	17,0	13,6	25,0	26,6	17,9
	above 6000	15,8	15,6	27,3	25,6	15,7
	above 1500 (aggregated)	17,0	13,8	25,5	26,4	17,3
	total	17,3	13,5	25,2	26,6	17,4

Own calculations based on data from microm.

4.4 Overall assessment of the environmental conflicts of the physical inventory across all protected interests

The traditional analysis in regional science and urban economics has been based on GDP per capita as the central variable describing growth and welfare. From an environmental viewpoint this narrow understanding of wealth does not suffice the idea of stainability since investment into the built environment across space always implies variable external costs to be covered by the stock of local nature resources. Hence, the specific local environmental costs need to be quantified appropriately. In the Frankfurt / Rhine-Main area locations (planning areas) are subject to a strategic environmental assessment in which they are classified according to environmental and legal restrictions. The respective maps are saved in a geo-data base and suggest the potential of a meaningful complement to economic grid data. The so-called spatial impedance data base for the Rhine-Main region consists of about 2,100 areas, about 95% of these areas being smaller than $1km^2$. Consequently, there is a variable resolution in the spatial impedance dataset while there is a constant one (one square kilometre) in the microm dataset. This makes it technically difficult to directly link spatial impedance to the socio-economic microm database. A possible solution is to separate the spatial impedance analysis from the overall socio-economic inference analysis (chapter 5) and to examine the data descriptively with a view to the areal classes defined earlier. This approach is examined in this section.

First of all it can be stated that in the categorization of the areas in the Frankfurt / Rhine-Main region in relation to the spatial impedance in the classifications "insignificant", " significant", "very significant", "significant positive" and "very significant positive" are made. Further distinguishing features are the number of potential conflicts and restrictions. What kind of restrictions the individual areas are subject to in terms of availability, use and compatibility in the areas of spatial planning or the environment cannot be investigated here, as more detailed information is required.

If one considers the actual classifications used, which have been assigned to the areas, it becomes apparent that the categories with the attribute "positive" have not been assigned in the study area. Table 9 shows how the thematic units for the following analysis are formed. Furthermore, the connections between the actually applied coding of the Frankfurt/Rhine-Main region and the description of the content become visible.

Table 9: Classification of environmental conflicts

Code Survey	Classification	Code Database	Code Classification	Notes on the database
			E0	insignificant (0 conflicts)
			E0_K	insignificant (potential conflicts)
		E0_K1	E0_K1	insignificant (1-2 conflicts)
E0	insignificant with potential conflicts or restrictions		E0_K2	insignificant (3-5 conflicts)
		E0_K3	E0_K3	insignificant (3-5 conflicts)
		E0_K6		
		E0_R		insignificant (more than 6 conflicts)
			E0_R	insignificant (potential restictons)
			E1_K	significant (1-2 conflicts)
E1	significant with maximum 5 potential conflicts	E1_K1		
		E1_K3		
			E2_K	significant (3-5 conflicts)
E2	significant with 6 or more potential conflicts or re-strictions	E2_K6		
		E2_R		
			E3_K	very significant (more than 6 conflicts)
E3	very significant with up to 6 or more potential conflicts	E3_K1		
		E3_K3		
		E4_R	E4_R	very significant (restrictions)
E4	very significant with 6 or more potential conflicts or restrictions	E4_K6		
			E5_K	considerably positive (1 - 2 potential conflicts)
			E6_K	considerably positive (3 - 5 potential conflicts)
			E7_K	considerably positive (more than 6 con-flicts)
			E8_R	considerably positive ((restrictions))

Own adaptation based on data from Regional Authority Frankfurt /Rhein -Main.

In order to combine these data with the spatial structures considered in this report, the data were linked by means of processing. If such procedures are used, direct assignment is often only partially successful. Some surfaces are then assigned in parts to different grids. Therefore, the partial areas lying in a grid are combined according to their environmental categorization. Once the above steps have been carried out, the spatial distribution of the classified areas can be analysed according to population density (table 10).

A first glance at Table 10 shows that the proportion of most stressed areas (E3 and E4) in the Frankfurt/Rhine-Main metropolitan region is low. The shares of the total area are all well below 10%, and in most population classes even below 5%. At a first glimpse this would suggest that the environmental or planning resilience of the Rhine-Main region appears quite strong on average. Whether this also applies to all the classified sub-regions needs to be closer looked at. Therefore, only the areas with the classifications E0, E1 or E2 will be dealt with in the following manner:

- It is evident that insignificantly restricted areas (E0) have got their biggest share in less densely populated areas. With an increase in population density, their share decreases more and more, until it even falls below the 10% threshold in high-density metropolitan areas. Hence, in urban zones there is substantially less potential for further physical growth without environmental and legal restrictions.

- The areas classified as significantly restricted and showing up to 5 potential conflicts (E1) have a share of at least 30% in each settlement structure considered. As population density is rising, this increases. Even in metropolitan areas, the proportion of land used is 70%. Evidence from this finding would suggest an overall physical growth potential with a moderate restriction level for 30 to 60 percent of the entire area. As regards reliability of spatial impedance data this finding should be subject to further investigation.

- The areas classified as E2 (significant with 6 or more potential conflicts or restrictions) represent a less prominent problem for the less densely populated areas in relation to their total area. They account for less than 10% of the total area. From a population area of more than 1,100 inhabitants per km^2, the share rises above this threshold and increases in line with increasing population density. In high-density metropolitan areas, the share of this category is the same as in insignificantly restricted areas (E0).

Furthermore, attempts have been made to find explanatory approaches for the distribution of restricted areas by means of socio-economic indicators and correlation analyses at the grid level. However, these have not been found.

Table 10: Share of evaluated environmental area in total area, in %, 2016

		E0	E1	E2	E3	E4
Rural Areas	below 150	55.3	30.4	4.7	1.1	8.5
	150 up to 300	44.9	40.0	6.3	1.9	6.8
	below 300 (aggregated)	54.3	31.3	4.9	1.2	8.4
Peri-Urban Areas	300 up to 700	36.4	46.0	8.5	1.9	7.2
	700 up to 1100	28.1	54.7	8.6	2.1	6.5
	1100 up to 1500	27.4	53.0	10.5	2.0	7.0
	300 up to 1500 (aggregated)	31.6	50.5	9.0	2.0	7.0
Metropolitan Areas	1500 up to 3000	22.8	57.5	13.1	1.2	5.4
	3000 up to 6000	15.2	61.9	19.5	0.7	2.6
	above 6000	6.2	69.4	24.0	0.2	0.3
	above 1500 (aggregated)	17.6	60.8	17.1	0.9	3.6

Characteristics over 10% of the total area.

Own calculation based on data from Regional Authority Frankfurt /Rhein -Main.

5 Evaluation of various influences on regional growth

In order to determine the influence of explanatory variables on changes in prosperity, many research approaches often apply the stochastic methods of econometrics. In the past, empirical macroeconomic models were the scientific focus. However, implications arising from the geographical proximity of economic agents have not been taken into account in these approaches. Due to the methodical progress in the last decades it is now also possible to model spatial relationships and to take these into account in the estimation procedure. This also makes it possible to estimate not only the direct influences, but also the indirect effects exerted by and on neighbouring spaces. Advanced spatial econometric modelling combined with a substantially improved spatial database (e.g. grid data, neighbourhood data, satellite images etc.) opens doors for an unprecedented precision in the estimates and thus a remarkably enhanced information base for policy decision. Therefore, the study at hand makes use of this important advantage.

In this study we use the variance in the grid data to obtain precise estimates by spatial econometric modelling. If using coarse averages (such as NUTS 2 data) the real variance at the neighbourhood level would be unobservable and estimates may be very different. More importantly we want to show how welfare is determined by different relevant predictors. The theory behind is to be explained as follows:

The overall aim of policy in democratic market economies is to enhance sustainable welfare. Sustainable welfare comprises more than just income but rather an improving and durable quality of life: Improving due to important technological innovations and durable due to an efficient allocation of natural resources. Since quality of life is also largely affected by subjective and highly individual criteria (e.g. health and mental status, age etc.) it is, however, hard to find a common definition of that category and hence to identify a representative variable for statistical analysis. Disposable income is therefore still the most often used indicator describing welfare. This variable is certainly more meaningful than just GDP per capita but it is still far from encompassing something like truly sustainable welfare, especially for highly aggregated data. A mathematically generated composite variable consisting of disposable income and an environmental resilience variable would be desirable but with the data available it is technically not possible at this stage (see earlier). Therefore, the following analysis does not directly consider the sustainability component of growth. For that purpose it is to be referred to chapter 4.4.

In the following econometric study the prior assumption of relationships had been first cast into a theoretical model. This model says that (sustainable) welfare depends on a number of important predictors which are e.g. the strength of the local economy, employment, infrastructure, the history of the social environment and the influence of neighbour communities in terms of Tobler's law[2]. Specifically for business and labour the local density of commercial units (hence the activity level), the level of unemployment and demand-relevant variables may serve as suitable predictors. These variables are all covered by the RWI Geo Data fed by the microm database. The model type applied is the Spatial Durbin Model. To show the spatial interaction the econometric analysis will be complemented by a commuter balance analysis among municipalities of different areal classes to detect important local push and pull forces between rural, peri-urban and urban area types.

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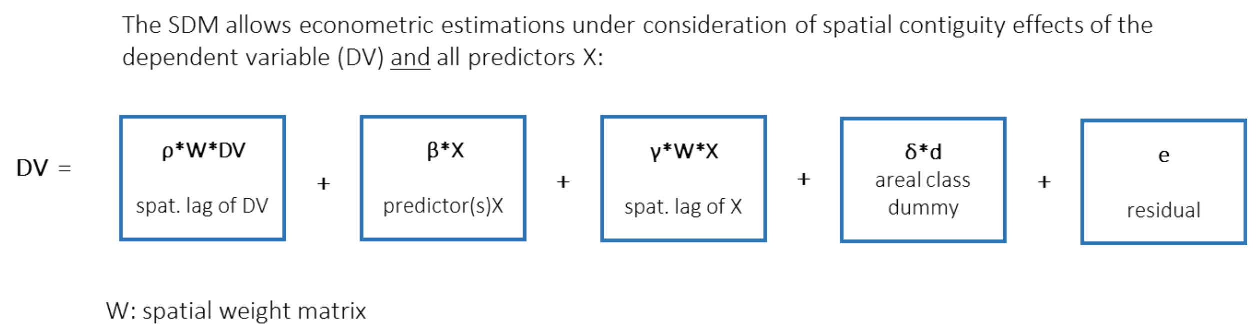
[2] "Everything is related to everything else, but near things are more related than distant things" (Tobler's law)

5.1 The spatial Durbin model

The spatial Durbin model generalizes the spatial lag and the spatial error model and hence includes both, spatial correlation in the lagged independent variables as well as spatial correlation in the error term (Anselin 1988). That is why the spatial Durbin model allows for neighbouring purchasing power per inhabitants to determine the price purchasing power per inhabitants.

Figure 8: Description of the components of the Spatial Durbin Model (SDM)



Overall, three different kinds of effects on the dependent variable are assumed:

- Direct effects, i.e. the standard effect of explanatory variables
- Indirect effects, i.e. the spatially weighted average effects of explanatory variables and spatially lagged dependent variable on the dependent variable
- Total effect, i.e. the sum of indirect and direct effects.

5.2 Estimation of the model

The spatial Durbin model, selected for this study, occupies an interesting position in spatial econometrics. It is the reduced form of a model with cross-sectional dependence in the errors, but it may be also used as the nesting model in a more general approach of model selection. In the first case, that is the equation where we solve the Likelihood Ratio test of Common Factors.

Based on the theoretical considerations, as structured earlier, a respective stochastic estimation is made in order to determine factors influencing disposable income per capita. Disposable income is not discounted by environmental costs/restrictions, hence estimates of the following econometric analysis have to be reflected by local data of spatial impedance or other data indicating the respective level of environmental resilience.

However, an important component that considerably improves precision of estimates in the following econometric analysis is the spatial influence across grids. In order to include spatial contiguity or distance effects into the estimation, a variable is formed to measure the distribution in space.

In addition, the spatial position of the individual parameters will be incorporated via a spatial weight matrix. The spatial units consist of grids with a length of the edge of 1km. The spatial Durbin model is used to connect and simultaneously estimate the explanatory content variables and the spatial variables.

The disposable income per capita will be determined by following content variables:

Table 11: Explanatory Variables

Commercial density	Number of businesses divided by the number of inhabitants multiplied by 100.
Migrant background	Share of households with foreign head of household in all households in a region, measured in %.
Upper-class cars	Share of passenger car segments upper middle class and upper class in passenger cars in a region, measured in %.
Unemployment	Unemployment Rate, measured in %.
Loan default	Percentage of households with the characteristic "slightly above-average probability of non-payment" and "above-average probability of default" in %.

The spatial variable Dummy (1-8) is coded as categorized in the following table:

Table 12: Coding of Dummy (1-8)

Category	Code	Population density, estimated by a KDE
Rural	1	<=150
	2	150 < x <=300
Peri Urban	3	300 < x<= 700
	4	700 < x<=1100
	5	1100 < x<=1500
Metropolitan Areas	6	1500 < x<=3000
	7	3000 < x<=6000
	8	>6000

The regional weight matrix, necessary for the estimation of the spatial contiguity effects, is built from the distance matrix of the grids. In a first estimation approach, disposable income per inhabitant (in its logarithmic form) is explained by the following variables: Commercial density, migrant background, upper-class cars Unemployment, Loan default, Dummy (1-8).For the regression, it is assumed here that the spatial lag is 1, so that only the adjacent neighbours are taken into account in the estimate. In the following table estimated coefficients of regression are displayed. The direct effect reflects the estimate without considering the spatially "lagged" variables, while the indirect effects reflect the influence of the "lagged" variables. The overall effect is obtained by adding the two effects.

Table 13: Results of Regression 1

	direct	indirect	total
(Intercept)	1,38030		
Commercial density	-0,00004	0,00011	0,00008
migrant background	-0,00143	0,00246	0,00102
upper-class cars	0,01137	-0,00049	0,01088
Unemployment	-0,01832	0,00872	-0,00960
Loan default	-0,00106	-0,00014	-0,00120
Dummy (1-8)	-0,00223	0,00649	0,00426

Own calculations based on data from microm.

By and large, the estimated coefficients reflect expected but also surprising results:

- Commercial density: Since the place of residence and the place of work do not normally coincide, it is not surprising that the direct effect is slightly negative and the indirect positive concerning the number of businesses.

- Migrant background: Foreign families and their local demand seemingly play an important positive role, even though there are social reservations; in fact, as the estimates show, their earnings and consumer behaviour contribute to the overall prosperity of a region (negative direct effect, positive indirect effect, positive overall effect).

- Upper-class cars: Vehicles represent status and prosperity, so positive direct and overall effects can be expected. As the neighbouring regions compete with the directly observable units, the overall effect may be reduced by minor indirect effects.

- Loan default: If loans are no longer repaid, this naturally triggers negative effects, both, directly as well as indirectly.

- Dummy (1-8): Why a negative direct and positive indirect effect is estimated for this variable cannot be explained logically from this relationship. However, it has to be stated that there is a positive overall regional impact. This can be interpreted that there will be an increasing effect on the regional income per capita the more densely populated a region gets. This variable can be interpreted in terms of a regional elasticity.

Even though the estimation results appear important and interesting, the data contain even more specific spatial information. In order to obtain detailed insight into the status of the variable “Dummy (1-8)”, further regressions are run in which the above variable is replaced by binary dummy variables that encompass rural, peri-urban and urban areas.

- The variable "Rural dummy (binary)" gets the value 1, if dummy (1-8) assumes values below 3, otherwise it has the value 0. It thus summarizes all rural areas.

- The variable "Peri-urban dummy (binary)" gets the value 1 if dummy (1-8) assumes values between 3 and 5, otherwise it has the value 0. It summarizes all peri-urban areas.

- The variable "Metropolitan dummy (binary)" gets the value 1 if dummy (1-8) assumes values above 5, else it has the value 0. It summarizes all metropolitan areas.

Table 14: Results of Regression 2, 3 and 4

	direct	indirect	total
Regression 2			
(Intercept)	1,37380		
Commercial density	-0,00004	0,00010	0,00007
migrant background	-0,00146	0,00266	0,00120
upper-class cars	0,01154	0,00016	0,01170
Unemployment	-0,01846	0,00891	-0,00955
Loan default	-0,00105	-0,00007	-0,00112
Rural dummy (binary)	0,00555	-0,01856	-0,01301
Regression 3			
(Intercept)	1,34320		
Commercial density	-0,00004	0,00010	0,00006
migrant background	-0,00146	0,00290	0,00144
upper-class cars	0,01169	0,00094	0,01263
Unemployment	-0,01853	0,00893	-0,00959
Loan default	-0,00104	0,00001	-0,00103
Peri-urban dummy (binary)	-0,00078	0,02248	0,02170
Regression 4			
(Intercept)	1,34920		
Commercial density	-0,00004	0,00008	0,00004
migrant background	-0,00145	0,00290	0,00145
upper-class cars	0,01150	0,00129	0,01278
Unemployment	-0,01839	0,00879	-0,00960
Loan default	-0,00105	-0,00003	-0,00108
Metropolitan dummy (binary)	-0,00630	0,00202	-0,00428

Own calculations based on data from microm.

The coefficients for the content variables in regressions 2 to 4 are close to the estimates displayed in regression 1, while the spatial variables react quite differently in the estimates. Since the content variables in the first regression beh9ave in a similar way as compared to regressions 2 to 4, the content relationship can be regarded as assured. By comparing the results of the spatial variables of the first regression with the results of the spatial variables in the other regressions the spatial effects can be isolated.

Table 15: Total effects of the spatial variables

Regression1	Dummy (1-8)	0,00426
Regression 2	Rural dummy (binary)	-0,01301
Regression 3	Peri-urban dummy (binary)	0,02170
Regression 4	Metropolitan dummy (binary)	-0,00428

Own calculations based on data from microm.

In the regressions 2 to 4 only one spatial variable is evaluated on at a time. A comparison of the three spatial elasticities reveals important effects that deserve closer consideration. We find a negative elasticity for rural areas, while the estimate for peri-urban areas suggests a relatively strong positive elasticity. The effect for urban areas is close to zero.

Different spatial production structures at local scale may be cited as possible explanations. These cannot be further investigated in this context since there are no specific sectoral data available.

The place of residence and the place of work often do not coincide in these small grid units especially in metropolitan areas. Therefore the probability that the working place is in a metropolitan grid, while the worker's residence is in a peri-urban area appears quite high. In order to investigate this thesis further, a complementary commuter analysis will be carried out below (chapter 6). Since the basic commuter data are not available at the grid level, this is carried out at the level of the administrative municipalities and then linked to the different areal classes by cluster analysis.

The following graph summarizes the effects of the individual variables on disposable per capita income. The individual signs indicate the direction of the influence in regressions 1 to 4. In order to implement environmental or planning restrictions, the disposable income needs to be discounted correspondingly in grids with such constraints.

Figure 9: Qualitative influence of covariates on the Disposable income per capita

Covariate	+/- tendency		() weak values	
Regression No.	1	2	3	4
Commercial density	(+)	(+)	(+)	(+)
Migrant background	+	+	+	+
Upper-class cars	++	++	++	++
Unemployment	--	--	--	--
Loan default	-	-	-	-
Dummy (1-8)	+			
Rural dummy (binary)		--		
Peri-urban dummy (binary)			++	
Metropolitan dummy (binary)				-

5.3 Remarks on the significance of the model

The spatial Durbin model generalizes the spatial lag (a model that includes spatially lagged independent variables) and the spatial error model (a model that explains spatially lagged residuals) and hence include both, spatial correlation in the lagged independent variable as well as spatial correlation in the error term. The test-statistics of the likelihood ratio (LR) test as well as the test-statistics of the Lagrange multiplier test help to identify whether the spatial Durbin model explains the data better than a standard spatial lag (SAR) or a spatial error model (SEM).

Some of the coefficients of the spatially lagged independent variables in the spatial Durbin model are significantly different from zero. Therefore, the likelihood ratio test is used to test whether the spatial Durbin model is more appropriate than a spatial lag model. The LR test is a test of the model with and without the spatial lag. The reported LR suggests that the addition of the lag is an improvement compared to a model without spatial lags included (LR-test value = X; p-value = 0). The LM test for residual autocorrelation points to a rejection of the spatial error model with a relatively low test-value and an insignificant p-value.

If the quality of the four regressions is to be compared with each other, the log-likelihood and the Akaike Information Criterion (AIC) can be used as a goodness of fit criteria. The larger the values this statistic gets, the better is the significance of the model. If this rule is applied, the first model is the best of all three, while the results for regression models 2 to 4 are very similar: the statistics for regression 2 are slightly better as those for regression 4 and regression 3.

6 Commuter analysis of the Frankfurt Rhine-Main area

6.1 Data source and general overview

In order to shed light on the specific spatial economic interaction between urban, peri-urban and rural areas of the Frankfurt/Rhine-Main region, a special commuter analysis will complement the spatial econometric analysis discussed earlier. The following analysis is based on commuter data at municipal level provided by the Federal Employment Agency. These data are determined by the employees subject to social insurance contributions. Corresponding data are collected on the reporting date of June 30 of each year. The following analysis first compares the data from 2016 with those from 2005.

In order to get a first impression on the dominant computing pattern, the following categories are formed for an initial overview:

Employees commuting

a. within the municipalities of Frankfurt/Rhine-Main region,

b. between remaining municipalities of the federal state of Hesse and the Frankfurt/Rhine-Main region,

c. between municipalities of the federal states bordering Hesse (NRW, Baden-Württemberg, Rhineland-Palatinate, etc.) and the Frankfurt/Rhine-Main region,

d. between municipalities of all the other federal states (, Schleswig-Holstein, Mecklenburg-Vorpommern, etc.) and the Frankfurt/Rhine-Main region.

Table 16: Comparison of aggregated commuter flows

		Commuters	Frankfurt/ Rhine-Main	remaining Hesse	neigbouring federal states	Long-Distance Commuting
Commuting Direction	**Year**	**Persons**	**in % of the commuting Persons**			
into Frankfurt/ Rhine-Main	2016	794085	53,9	19,2	12,4	14,5
out of Frankfurt/ Rhine-Main	2016	575421	74,4	9,4	6,5	9,7
into Frankfurt/ Rhine-Main	2005	649234	56,4	20,5	17,9	5,2
out of Frankfurt/ Rhine-Main	2005	443637	82,5	7,6	8,6	1,3

Own calculation based on data from Bundesagentur für Arbeit.

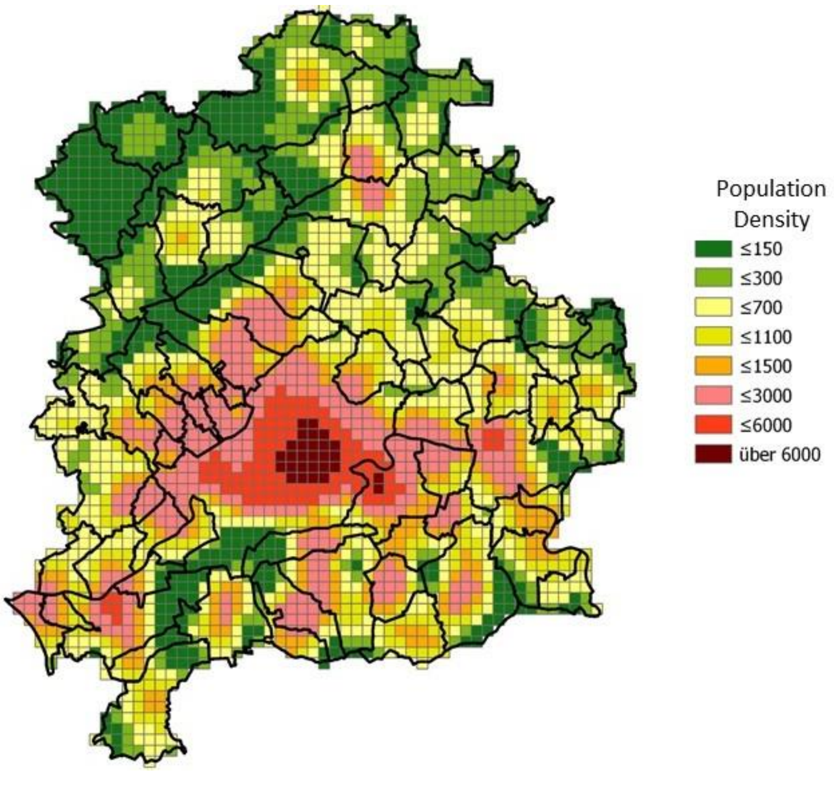
As one can expect, due to economic growth commuter flows have also increased between the observation years. Analogous to other Metropolitan regions, the Frankfurt/Rhine-Main region has a net influx on commuters. Between the dates of observation, the relative number of commuters coming from Hessian municipalities outside the Frankfurt/Rhine-Main region amounts to about 20%. Commuting from and to the direct neighbour states has decreased while long distance commuting is increasing. For the actual purpose of the study at hand, the commuting patterns inside the Frankfurt/Rhine-Main region is more interesting, especially when viewing commuting among the specified functional classes of space (urban, peri-urban and rural).

6.2 Commuting on the local level

6.2.1 Methodical approach

It is also possible to combine the information on the administrative units with the spatial data on the population structure, see Figure 10. The extent to which different population structures characterize administrative units can be seen here.[3]

Figure 10: Relationship between homogeneous (grids) and administrative (communities) units in the research area, 2015



Own calculations based on data from microm.

In order to investigate the spatial distribution within the municipalities more efficiently, the remote rural areas (less than 150 inhabitants per km^2) and more densely inhabited rural space (150 to 300 inhabitants per

[3] If one wants to leave the visual level in order to obtain quantitative data, it is possible to achieve this by using a similar geo process like in chapter 4.4.

km²) are combined at the municipal level to form an aggregate of less than 300 inhabitants per km². Aggregation is also applied for metropolitan areas, which are grouped into a group with more than 1500 inhabitants per km². The spatial breakdown per municipality is then as follows.

Table 17: Spatial Distribution for Commuter Surveys at Community Level

Category	Population density, estimated by KDE
Rural Areas	<=300
Peri-Urban 1	300 < x<= 700
Peri-Urban 2	700 < x<= 1100
Peri-Urban 3	1100 < x<= 1500
Metropolitan Areas	>1500

For each municipality, the proportions of the total area can be determined in the density classes. In order to further compress the information and to summarize similarly structured municipalities, the municipalities have been clustered according to these shares. For this purpose it seems reasonable to consider 8 clusters. They are characterized in the following table by the mean values of the individual parts (table 16). Figure 11 shows the municipalities on a map according to their cluster affiliation.

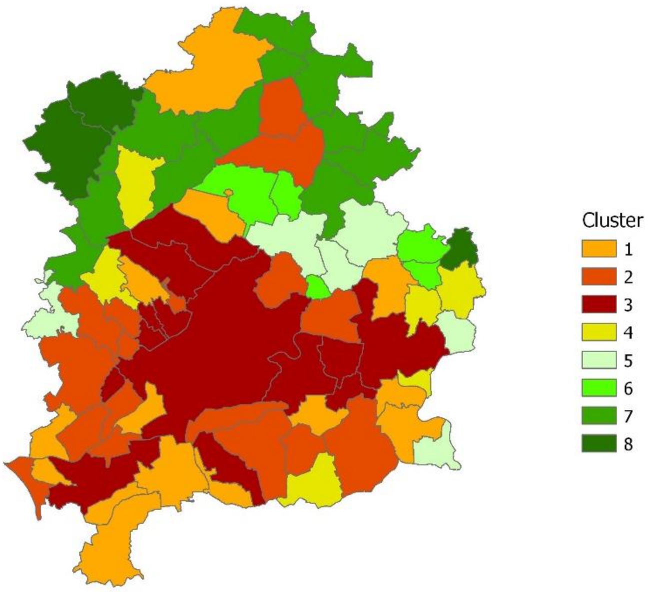
Table 18: Community Cluster, their Size, and average regional Shares, in %, in 2015

Cluster	Number of communities	Rural Areas	Peri-Urban 1	Peri-Urban 2	Peri-Urban 2	Met
1	14	2,5	7,4	17,3	61,0	11,8
2	17	1,0	8,0	9,8	21,4	59,7
3	13	0,0	1,8	3,1	5,0	90,2
4	6	0,4	9,0	49,7	40,7	0,2
5	7	6,1	46,9	47,0	0,0	0,0
6	5	4,1	95,9	0,0	0,0	0,0
7	11	46,9	51,1	2,0	0,0	0,0
8	4	100,0	0	0,0	0,0	0,0

Own calculations based on data from microm

Most prominent classes.

Figure 11: Municipalities in Frankfurt / Rhine-Main region, according their affiliation to a cluster



Own calculations based on data from microm.

6.2.2 Results

Commuter flows on a relatively small scale show how many working people live in the municipality and where they work. As explained above, in this study, the interest is not focused on the individual community, but on the spatial category. People commuting within a municipality are not included in the following analysis.

Table 19: Community Cluster, their Size, and average regional Shares, in %, in 2015

Cluster Group	Number of commuters	Departed from Group x Figures are % of all incoming commuters							
Incoming Commuters		1	2	3	4	5	6	7	8
1	32044	12,1	22,0	50,1	4,5	4,1	1,7	5,0	0,6
2	71006	12,4	24,9	44,0	4,7	4,8	2,1	6,9	0,1
3	300093	15,3	29,2	37,8	5,4	5,5	2,0	4,1	0,7
4	8936	10,1	23,4	39,4	4,5	5,8	2,8	9,5	4,5
5	7553	12,3	22,5	31,5	4,8	10,2	6,7	11,4	0,6
6	3008	9,5	27,7	22,9	4,8	12,4	4,5	16,8	1,4
7	5030	12,0	16,5	15,9	10,5	2,7	2,7	26,4	13,1
8	299	3,7	0,0	10,7	23,4	0,0	0,0	41,5	20,7
Cluster Group	**Number of commuters**	**Arrived from Group Figures are % of all outgoing commuters**							
outgoing commuters		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	61335	6,3	14,4	74,9	1,5	1,5	0,5	1,0	0,0
2	117873	6,0	15,0	74,4	1,8	1,4	0,7	0,7	0,0

3	168164	9,5	18,6	67,5	2,1	1,4	0,4	0,5	0,0
4	22500	6,3	14,8	72,1	1,8	1,6	0,6	2,4	0,3
5	23079	5,7	14,9	71,6	2,2	3,3	1,6	0,6	0,0
6	8905	6,1	16,5	65,8	2,8	5,7	1,5	1,5	0,0
7	22350	7,1	21,8	54,6	3,8	3,9	2,3	6,0	0,6
8	3763	5,5	2,7	59,6	10,7	1,2	1,1	17,6	1,6

Own calculation based on data from Bundesagentur für Arbeit.

Highest score of commuters in %

2. highest score of commuters in %

The first three cluster groups have a lively commuter exchange among themselves. This applies to both, arriving as well as departing commuters. Groups 2 and 3 are closely connected. More than 77% of commuting in the Frankfurt / Rhein-Main area takes place between the municipalities belonging to those two Groups. In terms of their spatial classification, these communities can be regarded as municipalities with a high proportion of metropolitan or dense peri-urban areas.[4]

The municipalities in cluster groups 4, 5 and 6 show a similar commuting pattern as the municipalities in the first three groups (the more densely populated municipalities). Their sub regions, however, are less densely populated, so that they belong to the group of municipalities that have smaller and medium-sized peri-urban structures: They receive a larger proportion of commuters from the two communities of the first three categories, but have only a small number of commuters in their groups and among each other.

The communities in cluster groups 7 and 8 represent the primarily rural areas. With regard to commuters, it can be seen that these communities maintain a lively exchange among themselves. A reason might be longer distance and worse accessibility/public transport. However, it is still conspicuous that more than ten percent of commuters each from the communities of the first four cluster groups come to cluster group 7 in the. For cluster group 8, this statement only applies to the communities of cluster groups 3 and 4. The commuters from the primarily rural communities seek their destination in the heavily populated communities of cluster groups 2 and 3 (group 7) or only in cluster group 3 (group 8). It is also noticeable that more than 17% of commuters from group 8 travel to workplaces in group 7.

Looking at the ratio of commuters in- versus outgoing, it is noticeable that only the municipalities grouped in cluster group 3 have a commuter surplus with a factor of 1.78, while there are deficits in all other cluster groups.

The commuter analysis shows that the spatial interaction on the local labour markets (i) is dominated by strong pull factors of the metropolitan regions in the south of the study area (in particular groups 1, 2 and 3). However, this shows that (ii) the commuting flows are not exclusively directed towards the metropolitan regions. A significant part of the employees leave the metropolitan areas to work in the communities of the

[4] Group 2 comprises the larger cities Frankfurt, Offenbach and Hanau plus the Main-Taunus-Kreis, while group 1 largely consists of municipalities south of Frankfurt

various peri-urban areas. These flows are also smaller in absolute terms. The dense commuter networks that can be demonstrated in this area indicates that proximity to the place of work seems to be an important secondary condition in the choice of residence. (III) The attractiveness of metropolitan regions is so great that more than half of all commuters from rural communities commute to these regions. In the opposite direction (metropolitan and highly dense peri-urban areas to rural areas), commuter flows are very low, so there is no need for further investigation in this context. On the other hand, it is noteworthy that significant commuter exchanges take place over the borders of the rural communities can be observed. This may also be a sign of how strongly the world of work and living is interwoven.

7 Concluding comments

This analysis uses official data at community level as well as small-scale data at 1 km network level. This provides the ability to identify precise socio-economic patterns on a small spatial scale (1km2 grid). For example, these data can be used to classify spatial areas into urban, peri-urban and rural areas on the basis of population density. From a methodological point of view, it makes sense to use kernel density estimation as an analytical tool. Based on that, spatial structure comparisons of demographic phenomena can be carried out on the one hand.

On the other hand, it is also possible to identify and estimate causal relationships and spatial cause-effect relationships for several variables at neighbourhood level (1km^2 resolution). Regional econometric models (Durbin model) provide the tool to evaluate spatial synergies/dependencies for relevant variables such as purchasing power, commercial density, migrant background, unemployment rate, vehicle class preferences or creditworthiness.

On the basis of classifications based on spatial micro-data, it is possible to identify spatial components of economic networks. In this way, spatial interdependencies in the urban-rural continuum can be uncovered within the framework of a structural analysis.

For the Frankfurt/Rhine-Main area, it can be stated that the spatial structures have not changed significantly during 2005 to 2015. Population growth can be observed particularly in the metropolitan areas. The spatial density structures of 3,000 to 6,000 inhabitants show a clear increase in the number of inhabitants. Population growth can be also seen in the sparsely populated areas (less than 150 inhabitants per km^2). However, the increase at this level is too small to balance the slight decrease of the overall population in rural areas of about 2%. Furthermore, it can be observed that the demographic structure of the population is balanced across all areas in the region studied. Furthermore, with the increase in the population, the variable spatial impedance shows increasing vulnerability.

In the two econometric procedures executed, the content variables show similar estimates in explaining welfare (disposable income). However, it can be seen in particular that rural structures have a negative effect on the development of per capita income, while peri-urban structures have a strongly positive effect. The effect in metropolitan structures is almost zero. Since the place of residence and the place of work in these small research units often do not coincide in the metropolitan areas, distortions can occur. At the content level a striking and important result is the positive welfare effect of residents with migrant background. A limitation of the study has been the technical difficulty to directly link environmental resilience to income. It was only possible to run a descriptive analysis of the spatial impedance data available.

The commuter analyses show an increase in mobility between 2005 and 2015. It is particularly noteworthy that the frequency of commuting to non-adjacent federal states has increased significantly. At the level of the Frankfurt/Rhine-Main region, the communities in the metropolitan and the medium- and densely populated peri-urban areas show a close interdependence. This takes place not only between these areas but also within them. Rural areas appear more isolated when viewing commuter exchange.

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