PLUREL

Module 2

Module No. 2

October 2010

PERI-URBAN LAND USE RELATIONSHIPS – STRATEGIES AND SUSTAINABILITY ASSESSMENT TOOLS FOR URBAN-RURAL LINKAGES, INTEGRATED PROJECT, CONTRACT NO. 036921

D2.3.7

Response function for commuting

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Document status:

Draft:	Final
Submitted for internal review:	x
Revised based on comments given by internal reviewers:	x
Final, submitted to EC:	

SIXTH FRAMEWORK PROGRAMME

Contents

Abstract

Objectives/aims

The objective of WP 2.3.4 is to develop and apply response functions (RF). Together with projections of urban growth (from the spatially explicit M1 RUG model), RFs will contribute to an estimation of future changing conditions affecting land use functions.

The main objective of this WP is to identify and describe the interdependencies of different factors (variables) which are influencing the interactions between commuting and land-use issues. The results are developed into a response function. In rural-to-urban regions, commuting reflects the interaction between urban and peri-urban areas. Response functions should be useful in predicting future development, given that the main driving forces are identified and quantified (M1) for that purpose.

Methodology

This study introduces a new method for assessing the impacts of different urban structures on commuting patterns. *The response function of commuting* uses empirical data on commuting to illustrate and model the interaction between the urban core and the surrounding functional region. A monocentric model provides the basis of the response function, whereby spatial interaction between the urban core and its surroundings is assumed to be one-directional. The resulting distance decay curve for commuting illustrates how in-commuting to the core area decreases as a function of distance.

An important limitation on the use of the response functions lies in the availability of data at European level. Analysis and modelling of response functions is based on test regions for which data is available. For this reason, we are unable to quantify commuting for the whole EU region. Instead, we provide a generic response function, based on results from test regions for which data is available. A total of 30 response function analyses were performed (12 case study regions for various years).

Results / findings / conclusion

A response function enables the comparison of the level of in-commuting to city centres from the surrounding peri-urban area in several regions of different types. The response function output takes the form of a probability gradient. These probability gradients from test regions were aggregated into archetypical commuting curves for regions with certain, common structural characteristics based on the RUR typology (WP 2.1). The gradients should help us estimate the extent of functional commuting areas in cities and indicate the level of centralisation of workplaces in different rural-urban structures.

Popular science description of main results

Transport is a major source of greenhouse gas emissions. Nowadays, commuting accounts for around 1/3 of total travel. It is also the most important single factor determining daily travel patterns. Commuting intensity and patterns are very much dependent on the distribution of workplaces, housing and transport systems. Commuting is closely interlinked with the urban spatial structure. It acts as a cost factor influencing choices of location and is a result of location choices made by individuals and firms. Correspondingly, commuting is a measure of the spatial interaction in urban structures.

Urban sprawl tends to enlarge the functional regions of commuting and increase the population in car dependent areas. On the other hand increased mobility of labour is crucial for specialised employment markets and thus regional competitiveness.

The available origin-destination data on commuting enables the study of the attractiveness of the urban centre. In the analysis the gradient approach is applied to measure the commuting pattern originating from surrounding areas towards the centre.

Monocentric and polycentric urban forms differ considerably regarding commuting patterns. In monocentric regions, the interaction between the urban core and peri-urban is strong. In a monocentric structure, the major direction of commuting flows is towards the core. The concentration of jobs in one core supports radial transport systems and enables an adequate public transport system, at least through main transport corridors. Fast radial transport systems tend to enlarge commuting areas and increase commuting distances.

In a polycentric structure, proximity between centres means that there are competing employment clusters within travel range, and thus the commuting patterns may vary more. As a result the main cores have rather limited commuting areas. In polycentric regions distance to the core does not explain the variation in average commuting distances.

Classification of results/outputs:
For the purpose of integrating the results of this deliverable into the PLUREL Explorer dissemination platform as fact sheets and the associated documentation, please classify the results in relation to spatial scale; DPSIR framework; land use issues; output indicators and knowledge type.

Spatial scale for results: Regional, national, European	Regional, urban regions: Helsinki, Tampere, Turku, Pori, Copenhagen, London, Manchester, Liverpool, Cardiff, Norwich, Vienna, Leipzig
DPSIR framework: Driver, Pressure, State, Impact, Response	State, Impact
Land use issues covered: Housing, Traffic, Agriculture, Natural area, Water, Tourism/recreation	Traffic, housing
Scenario sensitivity: Are the products/outputs sensitive to Module 1 scenarios?	Yes, but not quantified
Output indicators: Socio-economic & environmental external constraints; Land Use structure; RUR Metabolism; ECO-system integrity; Ecosystem Services; Socio-economic assessment Criteria; Decisions	Urban form, RUR interactions
Knowledge type: Narrative storylines; Response functions; GIS-based maps; Tables or charts; Handbooks	Response function, maps, figures and text

How many fact sheets will be derived from this deliverable?	2

Introduction

Objectives of WP and links to other WPs:

The objective of WP 2.3.4 is to develop and apply response functions (RF). Together with projections of urban growth (from the spatially explicit M1 RUG model), RFs will contribute to an estimation of future changing conditions affecting land use functions. In most cases, generic RFs are represented based on the mathematical equations for regression models and gradients of urban centrality, population density and urban density, describing the relationships between urbanisation and the state of the land use function in question. In the case of commuting, the RF is generic in nature, being derived from regression function related to single cases with detailed data availability.

Specific products include indicators, mathematical equations, graphs and descriptive annotations. The addressees are the scientific community and European policy makers responsible for various planning and pressure related issues.

Contributions to PLURELs end-products:

- PLUREL XPLORER: Fact sheets for response function and impact assessment
- The response function for commuting is one of the inputs for the urban growth modelling using the RUG model in module 1. The RUG model produces the scenario-based artificial surfaces for NUTS 2 regions in Europe. In RUG modelling, the accessibility of cities is given a type of new index, taking account of both the probability of commuting to a city of that size and the travel time/cost along the transport network. This method is introduced in Deliverable 1.4.3 "Report on maps of land-use change projections for Europe" (Rickebusch 2009).
- It is expected to form a contribution to the policy brochure

Objectives of the response function of commuting

The main objective of this WP is to identify and describe the interdependencies of different factors (variables) which are influencing the interactions between commuting and land-use issues. The results are developed into a response function. Response functions should be useful in predicting future development, given that the main driving forces are identified and quantified (M1) for that purpose. An important limitation on the use of the response functions lies in the availability of data at European level. For this reason, we are unable to quantify commuting for the whole EU region. Instead, we provide a generic response function, based on results from test regions for which data is available.

Commuting intensity and patterns very much depend on the distribution of workplaces and housing areas. Accessibility is an important factor in company start-ups as well as in households' residential area decisions. Indeed, the shape and condition of the rural-urban region transportation network has major effects on the development of settlement patterns and vice versa. The pricing and supply of public transport influence the pattern and shape of these networks. Thus, they have a great effect on modal split, road traffic share and environmental pressure.

In rural-to-urban regions, commuting reflects the interaction between urban and peri-urban areas. Commuting is closely interlinked with the urban spatial structure. Directions of major commuting flows tend to depend on the alternatives. Based on the pure monocentric model, the only available alternative is commuting to the centre. In a polycentric urban region, employment is located in several places, which means more alternatives for workers. These alternatives are available through a transport network. It is expected that the location of cities, subcentres and infrastructure, as well as the size and shape of urban development, reflect major commuting flows.

A response function enables the comparison of the level of in-commuting to city centres from the surrounding peri-urban area in several regions of different types. The response function output takes the form of a probability gradient. These probability gradients were aggregated into archetypical commuting curves for regions with certain, common structural characteristics based on the RUR typology (WP 2.1). The gradients should help us estimate the extent of functional commuting areas in cities and indicate the level of centralisation of workplaces in different rural-urban structures.

Approach of response function of commuting

Commuting can be viewed as the most important single factor determining daily travel patterns, not only in terms of volume but also because commuting trips are relatively stable in space and time: the origin and destination of a commuting trip are stable and the majority of commuting trips occur regularly, at certain times of the day. These peak period traffic volumes are used in transport infrastructure planning, which makes commuting the main determinant of urban region transport systems.

Commuting intensity and patterns strongly interrelate with the distribution of workplaces, housing and transport systems. Commuting patterns are largely a result of location choices made by households and companies. On the other hand, commuting also acts as a cost factor influencing these choices (Sohn 2004, Rouwendal and Nijkamp 2004). The commuting distance reflects the spatial interaction between labour force and housing markets, which generates traffic in the transport system (Jansen 1993).

Changes in urban structure affect commuting patterns. Traditional compact cities are evolving into large urban areas with a dispersed structure. Today, traditional suburb-to-centre commuting represents just one slice of increasingly complex commuting patterns; contemporary polycentric urban regions are characterised by a much wider range of choices in terms of origins and destinations (Schwanen et al. 2001, Gutierrez and García-Palomeres 2007). It is unclear, however, how polycentric metropolitan structures affect travel behaviour. Some authors suggest that a de-concentrated structure leads to reduced commuting distances and times, while others state that polycentricity implies an increase in commuting distances, since these are significantly longer in the suburbs than in a central area. It is generally agreed, however, that spatial decentralisation, supported by car availability and thus higher rates of accessibility, enlarges the functional regions of commuting, irrespective of what happens to the lengths of individual commuting trips.

This study introduces a new method for assessing the impacts of different urban structures on commuting patterns. *The response function of commuting* uses empirical data on commuting to illustrate and model the interaction between the urban core and the surrounding functional region. A monocentric model provides the basis of the response function, whereby spatial interaction between the urban core and its surroundings is assumed to be one-directional. The resulting distance decay curve for commuting illustrates how in-commuting to the core area decreases as a function of distance. This curve gives us an idea of how the spatial structure and size of an urban agglomeration affect commuting patterns and whether the "traditional" centre-oriented commuting pattern holds true in different test regions. The RUR typology provides a fruitful starting point for the analysis of commuting, since commuting can be seen as an indicator of the interaction between urban and peri-urban areas.

The structure of the deliverable

In the following pages, we begin by introducing the material and methods of the response function. Then, the results for the test areas are presented, explained and analysed. Later, test area results are aggregated into archetypical commuting gradients for different RUR types. Temporal changes are also presented based on the cases for which data was available. In the latter part of the results section, the Leipzig case's regional results are shown in more detail. In the discussion section, the limitations and shortcomings of the methods used are explained.

Material and methods

The analysis was based on the available origin-destination (OD) data on commuting from several regions in Finland, Denmark, UK, Austria and Germany. These particular regions were selected because they represent different urban structures and sizes, thus making the comparison interesting. OD-datasets included information on the number of employees, their living places and their work places. *Employees* in this study were defined as working persons over 15-years old, but not full-time students, unemployed, retired or otherwise economically inactive citizens. Part-time workers and self-employed people were also included in the definition.

The Finnish datasets were derived from the Monitoring System of the Spatial Structure, which is a GIS database and planning toolkit developed by the Finnish environmental administration. This system offers register-based two-way commuting data for the whole of Finland, in five year periods from the year 1985. The data covers the entire country in 250 x 250 m grid cells and also provides data separately for the functional areas into which the country has been divided (Helminen & Ristimäki 2007).

Data from other countries was available through the websites of national or regional statistical centres. The level of aggregation in the datasets varied between countries as follows: in Finland, the data was available in 250 x 250 m grids covering the whole country. In England, the unit of analysis was the ward, which is a subdivision of a local authority drawn up for electoral purposes. In the remaining countries (Denmark, Germany and Austria), municipalities were used as units of analysis. OD-data was available covering several years, also making temporal analysis possible. The datasets used in this study are presented in Table 1.

Table 1. OD-datasets used in this study

Country	Cities	Source of data	Level of aggregation	Years
Finland	Helsinki, Tampere, Turku, Pori	The Monitoring System of Spatial Structure	250m x 250m grid cells	1985, 1995, 2003, 2005
Denmark	Copenhagen	Statistik Denmark (http://www.dst.dk/)	municipality	1995, 2000, 2005, 2008
UK	London, Manchester, Liverpool, Cardiff, Norwich	Office for National Statistics, census 2001 (https://www.nomisweb.co.uk/)	ward	2001
Austria	Vienna	Austrian Institute of Technology (AIT)	municipality	1971, 1981, 1991
Germany	Leipzig	Statistik der Bundesagentur für Arbeit, "special data request" (http://www.arbeitsagentur.de/)	municipality	2000, 2008

Data sources: Finland: SYKE/YKR; UK: National Statistics (Nomis: www.nomisweb.co.uk). Source: 2001 Census. Crown copyright 2004. Reproduced under the terms of the Click-Use Licence. 2001 Census, Output Area Boundaries. Crown copyright 2004. Crown copyright material is reproduced with the permission of the Controller of HMSO. Germany: © Statistik der Bundesagentur für Arbeit. Denmark: © Statistik Denmark.

Background

In the standard monocentric model, workplaces are concentrated in the urban core and identical people choose their place of residence by weighing up the costs of housing, commuting and other goods (Alonso, 1964, Mills, 1967, Muth, 1969). Today, traditional suburb-to-centre commuting represents just one slice of increasingly complex commuter patterns. Contemporary polycentric urban regions with a decentralised employment and polycentric structure are characterised by greater diversity regarding the origins and destinations of work trips (Gutiérrez and García-Palomeres, 2007, Schwanen et al, 2001).

The starting point for response function development is a monocentric urban structure where urban density and the distance to the centre are interlinked. In a monocentric structure, these are also dominant variables affecting the commuting distance.

In a polycentric structure, density and the distance to the centre are not as closely interlinked as in a monocentric structure. In a polycentric structure, high densities can be found at different distances from the main urban centre. In these cases, distance to the main centre is not as significant a variable as density or the distance to the subcentre.

Urban structure, the result of the geography and history of a region, is unique in each case. Different urban forms can be found in many sizes and shapes. It is therefore important to recognise elements that are site dependent and those that are universal. In a generic response function, site dependent local conditions are too diverse to be taken into account. On a universal basis, certain variables in urban structures are closely linked to commuting. Gravity and accessibility define the dimensions of a commuting area. Based on a monocentric model, the average commuting distance tends to increase as a function of the distance to the centre (figure 1). In general, the average commuting distance is low wherever urban density is high. The public transport system is also linked to urban density, enabling commuters to avoid travelling by car.

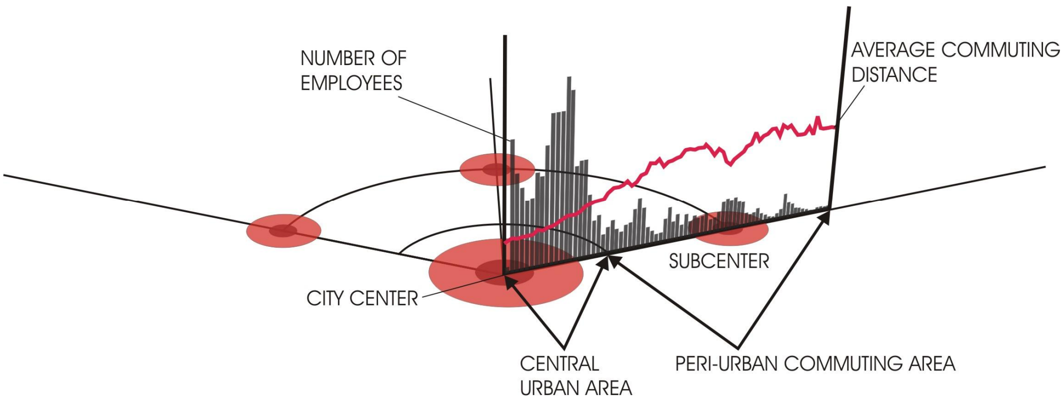

Figure 1. Gradient-based illustration of the average commuting distance and distribution of employees in an urban- peri-urban region. The graph is based on data from the Helsinki commuting area.

Based on empirical observations of the Finnish data, three different segments can be recognised in the urban-rural gradient that are of great importance to average commuting distances (Figure 1). The first of these is the central urban area in which dense housing and employment are mixed. In this area, average commuting distances are stable and quite clearly a function of distance to the centre. However, this may vary, depending on how concentrated jobs are in the central area.

The second segment is a subcentre, which is a dense urban area located inside the commuting area of a larger urban centre. Subcentres can be specified as areas with a high concentration of population and workplaces. The effect of subcentres on commuting can be understood in terms of islands of shorter average commuting trips within a larger commuting area. When an urban region evolves towards a polycentric structure, subcentres form their own commuting areas. This, however, depends on the size of the central urban area and how the subcentre is located in relation to the central urban area.

The third segment is a peri-urban settlement located inside the commuting area but outside the densely populated urban area or subcentres. In these areas average commuting distances are highest, because certain numbers of workers commute to the central urban area. The proportion of workers commuting to the urban centre decreases as the distance increases, but the few who do commute have a strong impact on the average commuting distance.

Density gradients are a common approach to estimate the decentralisation process in monocentric model. In the response function, the gradient approach was applied to measure the traditional commuting pattern, i.e. commuting to the centre from surrounding areas.

Commuting is a good measure of an urban structure because it links the distribution patterns of economic activities and settlement to transport. At regional level, the direction of major commuting flows depends on structural issues. The structure of economic agglomerations defines the destinations of major commuting flows. Density, alongside the fragmentation of the settlement structure, influences commuting distances. Transport systems facilitate mobility between the origin and destination.

The methodology of the response function analysis can be divided into four steps: 1) GIS-analysis, 2) data preparation in Excel, 3) modelling in SPSS, and 4) final visualisation in Excel and ArcGIS.

GIS analysis

The first phase, GIS analysis, began with the plotting on a map of coordinate data relating to employees' living places. In most cases, this was done by calculating the geometric centres for each of the units of analysis. In some cases, (UK cities, Leipzig year 2008) the coordinates of functional midpoints of wards/municipalities were also available and used. Then, the Euclidian distance between the city centre and each of the plotted midpoints was calculated.

The urban core area was defined by buffering the city centre with a 10 km radius circle. This rather coarse definition of an urban centre was justified because the analysis was performed at regional level; the aim was to define an area that stands out as an employment agglomeration of the central urban area, including both the central business district (CBD) and secondary employment agglomerations inside the city area. Commuting trips occurring inside the urban core, e.g. originating less than 10 km from the city centre, were excluded from the analysis. In order to enable a comparison between different test regions, the core circle radius was kept constant. Thus, no account was taken of the variation in the physical sizes of test cities. However, for a couple of smaller cities (Pori in Finland and Norwich in the UK) the core area was defined as a circle with a 5 km radius around the functional midpoint. Each municipality, ward or grid cell whose midpoint was within the defined circle was classified as a core area.

Based on the defined core area, the number of employees commuting to the core area in each unit of analysis was calculated. Then, the attribute table containing information on distances between each of the analysis units and the city centre, the total number of employees in each unit and the number of employees commuting to the core area in each unit, were summarised based on the distance information. The second step involved processing the summarised table in Excel. The table rows were classified according to the distance information, with a 1km interval.

Model

The third step involved modelling the attractiveness of the city centre as a commuting destination, using empirical data. Modelling was based on the "Commuting to a circle as a function of distance" (CCD) model, which in turn was based on logistic regression (see Collett 1991). The model's parameters were estimated for the case studies using the SPSS PROBIT procedure to fit a logistic regression. Here, the distance between the employee's living place and the city centre was an independent variable, explaining the dependent variable i.e. the proportion of the total working population commuting to the centre from each distance zone.

Parameters of the "CCD" model:

The CCD model has three parameters, S, π_S and B. This parameterisation was chosen in order to guarantee simple interpretations in terms of urban dynamics.

Parameter S

For the model, we define the city centre as a circle with radius of S. Due to the differing commuting character of the centre, we exclude commuting within the 'centre circle' and concentrate only on traditional commuting from the surrounding area to the 'centre circle'. Distances are measured to the midpoint of the 'centre circle'. This keeps the measurement of distance independent of the value of the parameter S.

Parameter π_S

The parameter π_S, which depends on the value of S, gives the proportion of commuting trips directed inside the 'centre circle' among all commuting trips starting at distance S from the city centre, i.e. from the edge of the centre. If π_S has a value of 50% then half of the commuting trips beginning from the edge of the 'centre circle' are directed inside the circle and the rest outwards.

Parameter B

Parameter B characterises the decaying effect of distance on a proportion of the commuting trips directed inside the 'centre circle'. The value of B is given as percentages. Typical values are 4% (in the Helsinki area) or 12% (in the Manchester area).

The model

Variable $\pi(d)$ is the proportion commuting inside the centre from those who live at distance d (km) from the city centre. The decaying effect on d of an additional km can be seen by comparing $\pi(d)$ and $\pi(d+1)$. A natural way of comparing proportions would be to use their odds (Collett, 1991). If B = 5 %, the odds corresponding to $\pi(d+1)$ can be obtained by decreasing the odds corresponding to $\pi(d)$ by 5%. This is done by multiplying the odds at d+1 by 0.95; in general by (100 - B)/100. Large values for B thus indicate a steep gradient, i.e. a rapid decrease in the proportions $\pi(d)$ as a function of distance d. However, the value will always be below 100%.

In the model, the proportion $\pi(d)$ is given as a function of distance d (km), with the parameters S (radius, km), π_S (proportion) and B (percentage):

$$\pi(d)=\left[1+\frac{1-\pi_S}{\pi_S}\left(1-\frac{B}{100}\right)^{S-d}\right]^{-1}$$

The model is defined only for those values of distance d that exceed S, the radius of the centre circle. By inserting $d = S$, we obtain the proportion of commuting trips into the centre circle at the edge of the centre circle, i.e. $\pi(S)$. A simple calculation shows that $\pi(S) = \pi_S$. As d increases, $\pi(d)$ will approach zero as long as B is positive (Figure 2).

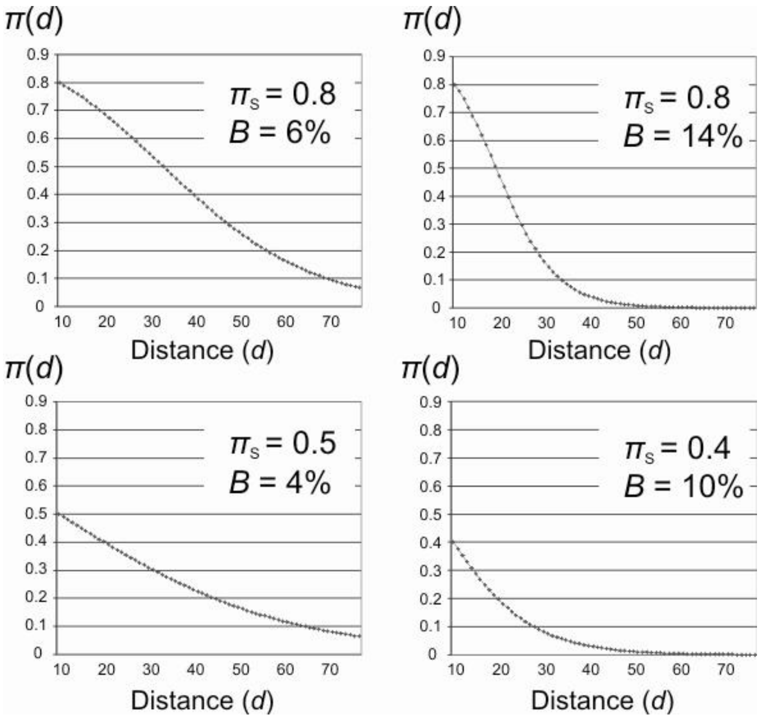

Figure 2. The curves given by the CCD model for four differing parameter value combinations. The centre radius parameter S is taken to be 10 km in all cases.

Visualisation of the results

The results of the model were then visualised in Excel. The observed proportions of working population commuting to the centre from each distance were represented as points, whereas the model-based probability of commuting to the centre from each distance zone was presented as a curve.

In order to facilitate the interpretation of the model, a couple of basic parameters were derived from the modelled curves and visualised as a plot chart in Excel. Parameter π_S reveals the probability of commuting to the core area at the edge of the 'centre circle' (having radius S). High π_S values indicate that most workers living in the vicinity of the city centre commute to the centre. Low π_S values suggest that there are options for the place of work in addition to the main centre. Parameter B characterises the distance decay effect of this probability and the value is given as a percentage. The smaller the value of B, the smaller the distance decay effect, indicating a stronger power of attraction in the urban core.

Finally, the empirical data was visualised as maps representing the proportion of employees commuting to the core area in each of the units of analysis. In order to assess the significance of each unit, the absolute number of employees commuting to the core area was visualised using the Flowmapper tool (http://dynamicgeography.ou.edu/flow/index.html).

Testing the method

In addition to the above described basic work flow, some experiments were performed in order to evaluate the robustness of the method. In order to assess the effects of different levels of aggregation in the datasets, Finnish data was analysed at several levels of aggregation, ranging from very detailed (grid cells) to rather coarse (municipalities as such and with 5 km intervals). German data was analysed both according to administrative borders and a regular circle (45 km radius) around the city centre. The results of these tests are discussed in the discussion section of this report.

Test site characteristics

The cities used as test sites for this study, provide different examples of urban structures and population densities. Two of our test sites, Manchester in the UK and Leipzig in Germany, are PLUREL case study regions, while the remaining cities were chosen based on data availability. The United Kingdom has a dense network of cities, many of them with a clearly polycentric structure. For example, the distance between Manchester and Liverpool is only around 50 km; together with several smaller cities, they form a polynucleated urban region. In such cases, commuting areas tend to overlap and each city centre has a rather limited area acting as a dominant commuting destination (see Champion 2001). The city of Cardiff has similar characteristics, since it is part of a coastal network of cities from Bristol to Swansea.

London and its surroundings form an individual polycentric "global mega-city region". It has one clear main centre and several sub-centres (Titheridge and Hall 2006, Nielsen and Hovgesen 2008). Although there are plenty of subcentres and the metropolitan area has become increasingly polycentric, the city centre remains the major employment concentration.

The last of the UK cities, Norwich, is different from its counterparts since it has a monocentric structure. This structure is common to the Finnish test sites which are all separated by at least 100 km. In general, Finland's larger cities tend to be more distant from one another, leading to monocentric urban form and large commuting areas.

Copenhagen in Denmark has similar characteristics as Helsinki in Finland. It is the dominant centre on the island of Själland and has a strong core area, in which the majority of workplaces are concentrated (Nielsen & Hovgesen 2005).

Leipzig and the adjacent Halle form an urban region with two centres. Vienna is a very dominant metropolitan region in Austria, with 1.6 million inhabitants.

Test sites and RUR typology

RUR typology comprises the quantitative classification of rural-urban regions in the EU 27 at NUTS3 level (deliverable 2.1.3). This typology is based on the viewpoint of spatial pattern and morphology (Loibl et al. 2008). RUR classes are as follows 1) *very large monocentric*, 2) *large monocentric*, 3) *medium monocentric*, 4) *urban polycentric,* 5) *dispersed polycentric* and 6) *rural*.

Test areas are classified as follows:

1.0 Very large monocentric: *London, Helsinki, Copenhagen, Vienna*
1.1 Large monocentric: *Tampere, Turku*
1.2 Medium monocentric: *Norwich, Pori*
2. Urban polycentric: *Manchester-Liverpool, Leipzig, Cardiff*

Monocentric RURs are regions with a core city area with no notable peri-urban sub-centres. *Urban polycentric* RURs are regions with core city (or cities) and peri-urban sub-centres. RUR-class *rural* refers to NUTS regions with dispersed small settlements without core cities. *Dispersed polycentric* refers to NUTS regions with a few medium sized core cities (Loibl et al. 2008). In the case of medium-size cities, commuting areas are small, which means that in *dispersed polycentric* regions cities tend to have separate commuting areas.

In some cases, NUTS3 level regions do not provide a good fit with actual urban functional areas. For example, in London the city is classified as *very large monocentric* while the surroundings are urban polycentric. The RUR typology, however, gives the basic morphological classification needed to interpret the results of commuting analyses.

Results

Commuting curves and model parameters for test sites

A total of 30 response function analyses were performed (12 case study regions for various years). Figure 3 presents 12 commuting curves, one for each study area. The data used for the UK curves is from the year 2001, Finnish data is from 2003, Danish data from 2000, Austrian data from 1991 and German data from 2000. The curves represent the modelled values, whereas the dots are real-life observations.

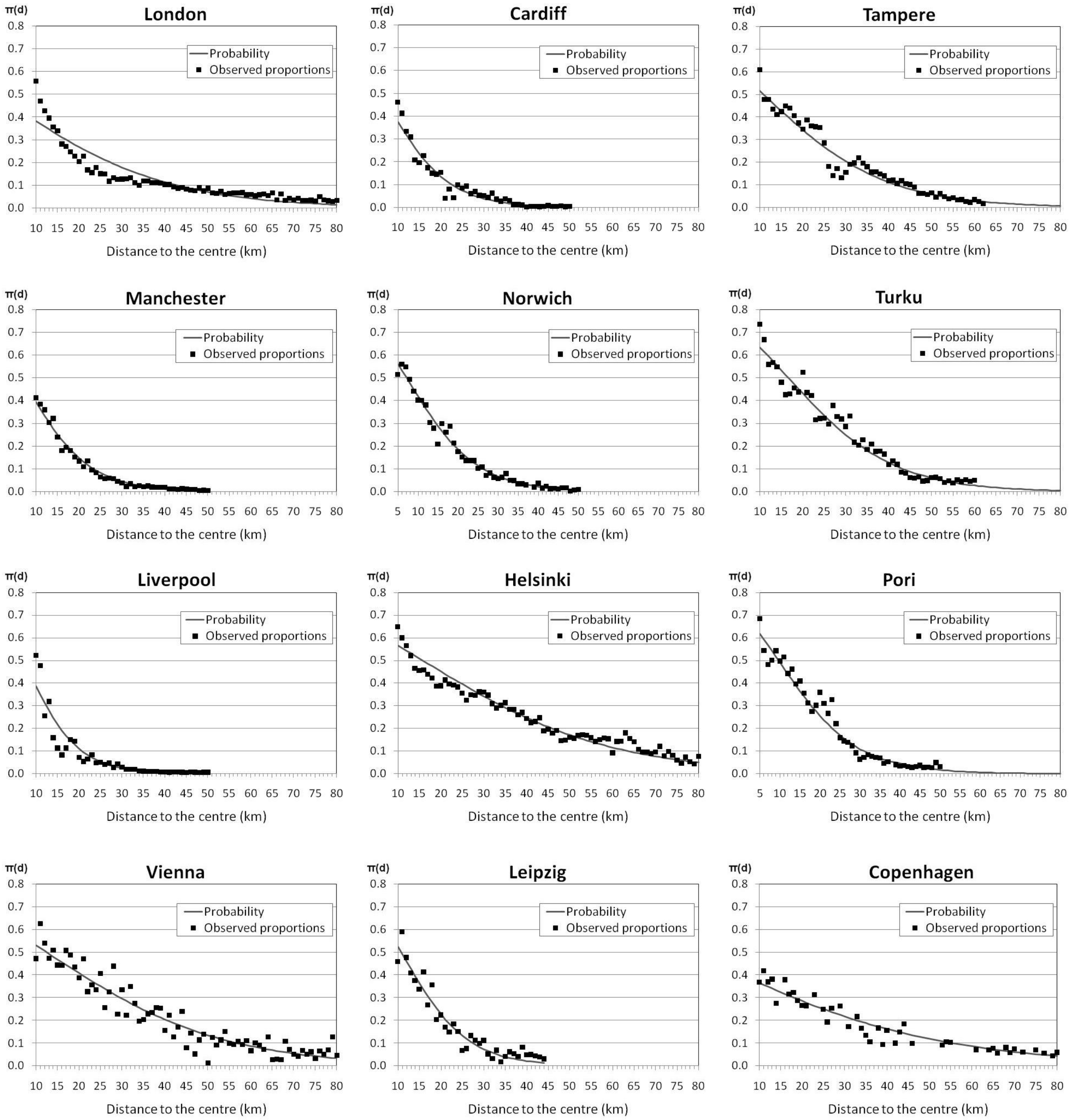

Figure 3. Modelled and observed proportions of employees commuting to the core area from various distances in different test regions. The horizontal axis represents the distance (km) between the employee's living place and the city centre. The vertical axis presents the proportion or probability of commuting to the core area. The radius of the

core area circle is 10 km in all cases, except for Pori and Norwich, which have a radius of 5 km.

In the case of the Finnish test sites, the curves reflect the monocentric structure typical of these cities. In such cases, the value of parameter π_S (the starting point of the curve, which is the probability of commuting to the core area at the edge of the 'centre circle') is above 0.5. In Turku and Pori, the value exceeds 0.6. Helsinki has the gentlest gradient, which means that its commuting area is very large and the friction of distance small. Still, at a distance of 65 km from the city centre, the probability of commuting to the core area is 10%. From the Finnish test sites, Pori has the steepest curve; a probability of 10% having already been reached at a 32 km distance from the city centre. This is a result of the small size of the city (about 100,000 employees in the commuting area) and a correspondingly delimited commuting area.

Also Norwich, Vienna and Leipzig have π_S values exceeding 0.5. The curve for Norwich is similar to Pori's, whereas Vienna's curve is reminiscent of Helsinki's. Despite the rather high π_S value, the curve for Leipzig reflects a high friction of distance. The probability of commuting to the core area already falls below 10% at a distance of 26 km. Thus, the commuting area around Leipzig is small, although employees living close to the centre mainly commute to the core area.

Apart from the city of Norwich, all of the UK cities present parameter values typical of polycentric cities: the probability of commuting to the core area at the edge of the 'centre circle' is close to or below 0.4. Manchester, Liverpool and Cardiff have rather steep curves, and the probability value falls below 10% at distances between 20 and 25 km from the city centre. London is different: the friction of distance is very small, and the gradient of the curve gentle, reflecting a very large commuting area.

The curve for Copenhagen did not follow our expectations: based on the city's characteristics and existing literature, the curve was assumed to be similar to Helsinki's, but turns out to be more reminiscent of the curve for London. According to this curve, the probability of commuting to the centre at the edge of the core area is low, but the commuting area is large. One explanation for this unexpected result could be the coarse municipality level data. As shown later, different levels of aggregation in the commuter statistics have an effect on the results.

The comparison between points (observed proportions) and curves (probabilities) reveals how well the model approximates to the real data from each distance zone. Although real-life observations in general follow the shape of the curve, there are some notable exceptions which require a closer look. The existing subcentres with strong employment, and on the other hand, remote areas with high rates of accessibility towards the core area, cause such exceptions. In the case of Tampere, the points in the 25-30 km distance zone are considerably below the curve. This is explained by the subcentre of Valkeakoski, located 27 km from Tampere. This subcentre is self-sufficient in terms of workplaces, which reduces the probability of commuting to the Tampere core area from those distances. In Helsinki, the opposite phenomenon occurs at distances of 60-65 km from the city centre. The city of Riihimäki is located 65 km from Helsinki and the train connection between these two cities is fast. This is reflected in the figure, with an increased proportion of employees commuting to the Helsinki core area at those distances.

In London, the curve fits poorly at distances below 40 km from the city centre. London is different from other test sites in terms of the physical size of its urban area, while the elasticity of its model curve is too low in areas close to the 'centre circle'.

The characteristics of the curves presented in Figure 3 are summarised in Figure 4. Here, the vertical axis represents the parameter π_S and the horizontal axis the parameter *B*. The cities located in the upper part of the diagram are those with concentrated employment. In these cases employees living close to the centre are mainly commuting to the core area (Helsinki, Turku, Pori, Tampere, Norwich, Vienna and Leipzig). Low π_S values suggest that the core area is not the only commuting destination. Such a decentralisation of employment is common in many contemporary cities (see Gutiérrez and García-Palomeres 2007; Muñiz et al. 2008); the test regions located in the lower part of the diagram are characterised by a polycentric urban form (Liverpool, Manchester, Cardiff, London, Copenhagen).

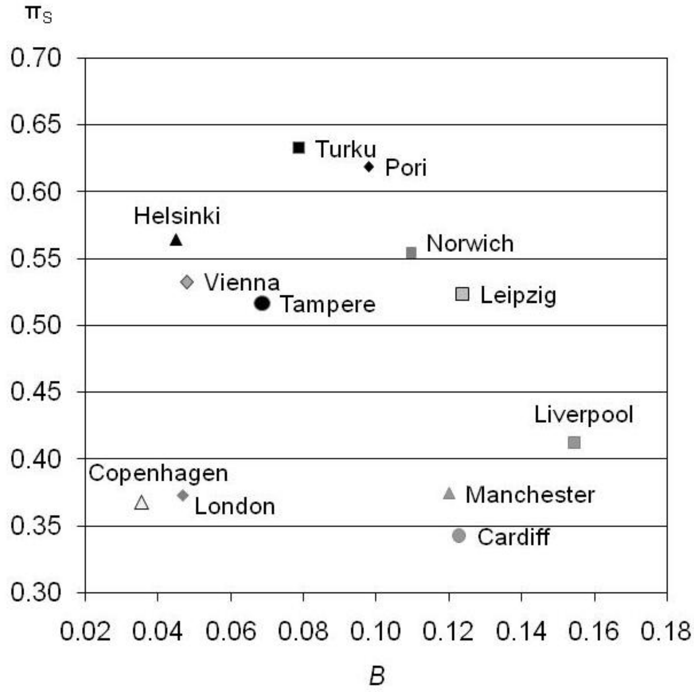

Figure 4. Model parameters plotted in a diagram.

Low *B* values indicate a small friction of distance, meaning that the probability of commuting to the core area decreases slowly. According to the results, this is typical of the test sites Copenhagen, London, Helsinki, Vienna, Tampere and Turku. In Pori, Norwich, Leipzig, Liverpool, Manchester and Cardiff the *B* value is rather high, indicating a compact commuting area, which is often related to the small size of the city or the existence of other overlapping commuting areas.

Archetypical commuting curves applied to the RUR typology

The RUR typology does not separate different urban polycentric structures. In polycentric urban structures, employees have access to several employment markets. The emergence of polycentric urban structures has been illustrated by Champion (2001). If a polycentric region has emerged from a fusion of previously independent centres with no clear hierarchy, it is expected that commuting areas will overlap and that each of the city centres will have a rather limited area where they function as a dominant commuting destination (Figure 5).

Champion (2001) also distinguishes between the centrifugal and incorporation modes, which emerge from expanding the monocentric city. In these cases, there is usually a clear hierarchy with one dominant agglomeration of workplaces and several rivalling sub-centres. These individual metropolitan areas are strongly suburbanised, with a large commuting hinterland (Champion, 2001; Muňiz et al, 2008). In addition to the existing RUR typology the class *Individual polycentric metropolitan* is needed to express the various shapes of the commuting curve. At the first stage, this class should include the biggest monocentric urban areas such as London, Paris etc. Among the archetypes, this class includes all monocentric cities with over 3 million inhabitants.

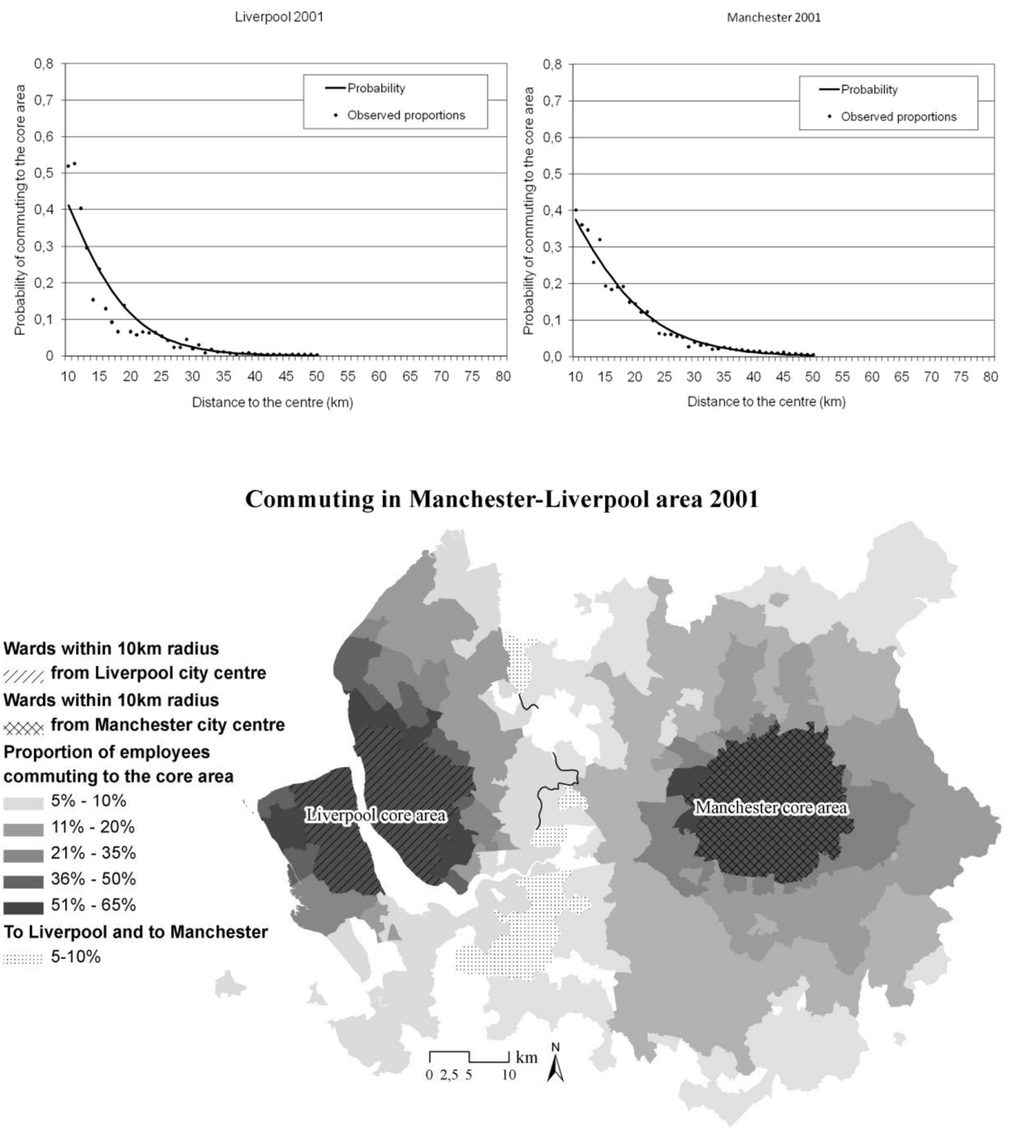

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Figure 5. Commuting gradients and map of commuting in the polycentric Manchester-Liverpool area.

In Figure 6 the different commuting curves are summed up to represent different RUR types. Typically, the curve for a *very large monocentric* urban agglomeration has a high value for probability of commuting to the core from neighbouring areas (curve A). This means that a high proportion of employees living close to the core commute there. In addition, the distance decay effect is weak, indicating that the commuting area is large and the core attracts commuters from distant areas. Usually, such a pattern is facilitated by an efficient transport infrastructure and high rates of accessibility.

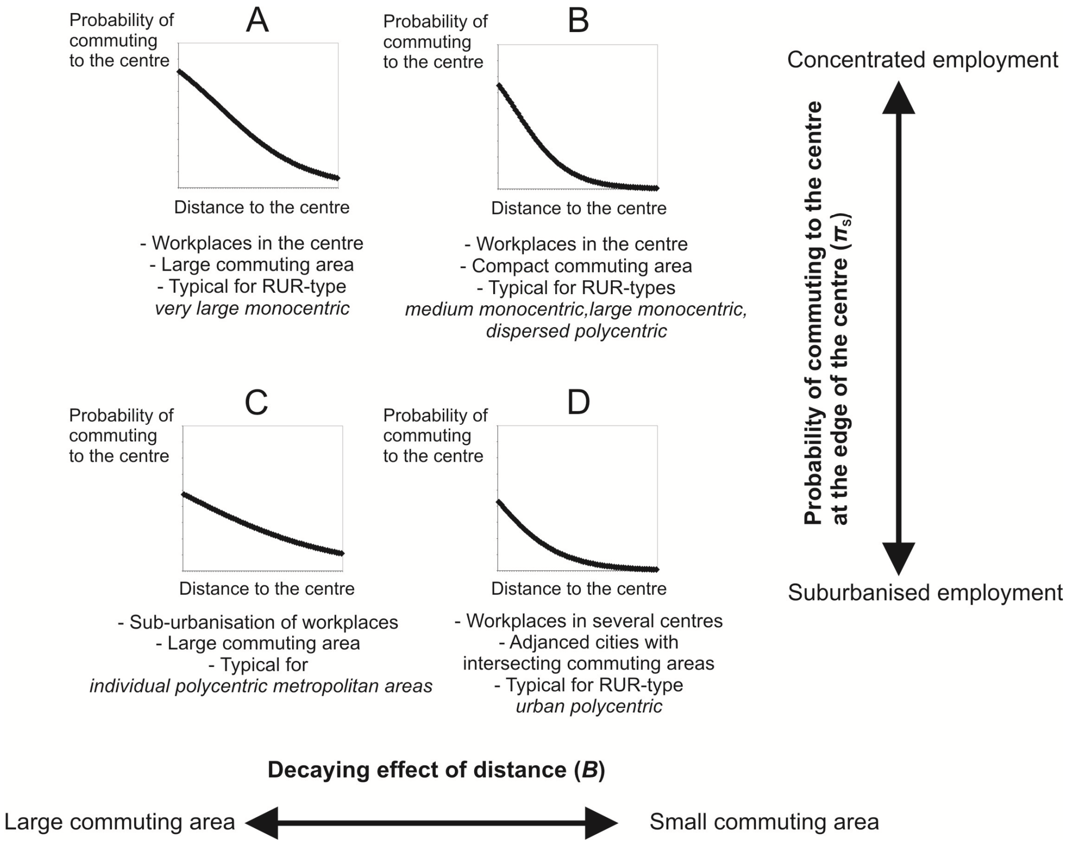


Figure 6. Common framework for commuting curves and urban form, summarising the results from the case areas presented in Figure 4.

The smaller the urban agglomeration becomes, the stronger the distance decay effect and the steeper the shape of the curve. *Large monocentric*, *medium monocentric* and *dispersed polycentric* types are typically represented by a steeper curve that still has a rather high percentage of employees commuting to the core from the edge of the core (curve B). Thus, the attractiveness of the centre is high but the commuting area is compact.

Lower probabilities of commuting to the core reveal that the employment structure of the urban agglomeration is dispersed among several locations. Thus, in addition to the centre, people living close to the core have other possibilities in terms of location of workplace.

Individual polycentric cities have evolved to become polycentric as a result of continuing growth and decentralisation processes (Aguilera and Mignot, 2004, Champion, 2001). Curve C illustrates the situation typical of large metropolitan areas, with one predominant centre and a large functional area, but with considerable numbers of workplaces located in sub-centres. Although the metropolitan area has become increasingly polycentric, the city centre remains the major employment concentration.

Urban polycentric agglomerations are usually polynucleated metropolitan areas which have several, equal sized cities with overlapping commuting areas (curve D). These areas are normally represented with a curve that has a rather low probability value with a strong distance decay effect. Here, the traditional centre-oriented commuting pattern is replaced by suburban-to-suburban commuting. None of the centres is necessarily dominant but, together, they form one large functional region with overlapping commuting areas.

Figure 7 represents aggregated curves for each RUR class based on the test area results. In reality, the majority of cities have a curve that is a mixture of these archetypes. There was no test site for *dispersed polycentric*, which refers to peri-urban polycentric NUTS regions with a few medium-sized cities. The archetypical curve was constructed based on the curve from the medium monocentric cities. We expect medium-sized cities to have small commuting areas.

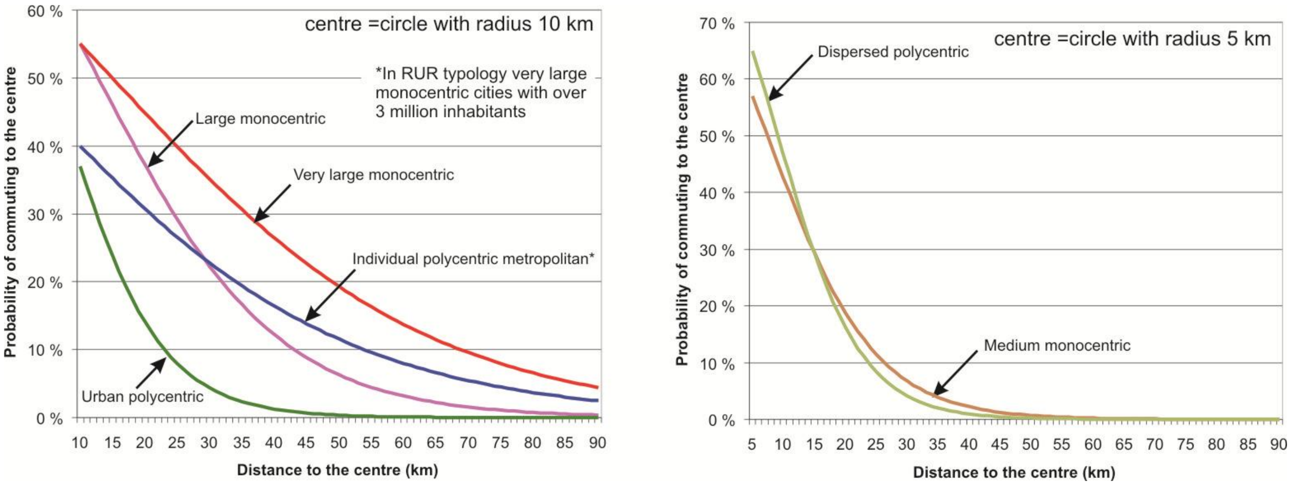


Figure 7. Archetypical curves for RUR types, derived from the results for the test areas

Changes in commuting trends

An analysis of temporal change in commuting trends was possible using Finnish, Danish, Austrian and German data. Figure 8 presents the changing patterns in the Finnish test sites, both as curves and as parameters. In Pori, the value of parameter π_S has changed little: at the edge of the 'centre circle' the probability of commuting to the core has decreased only a little. However, the probability of commuting to the centre at distances of 15-40 km from the centre has increased significantly since 1985.

In Helsinki, the value of π_S has decreased a great deal in ten years (between 1985-1995) which means that the centre has lost some of its appeal in neighbouring areas. This reflects the suburbanisation of workplaces; the traditional centre is no longer the only alternative for the location of workplaces. Indeed, during recent decades there has been considerable growth in new workplaces along the ring road area located 10-20 kilometres from the city centre. At distances greater than 30 km from the city centre, the probability of commuting to the centre has risen as a result of faster transport services, and the commuting area has became larger.

A similar trend can be seen in Turku and Tampere: the latest curve (2005) is the one running along the top. However, at edge of the 'centre circle' in these two cities the probability of commuting to the core area has been increasing since 1985.

In general, the trend at the Finnish test sites has been similar in the sense that the friction of distance has become smaller in distant areas, indicating the enlargement of commuting areas.

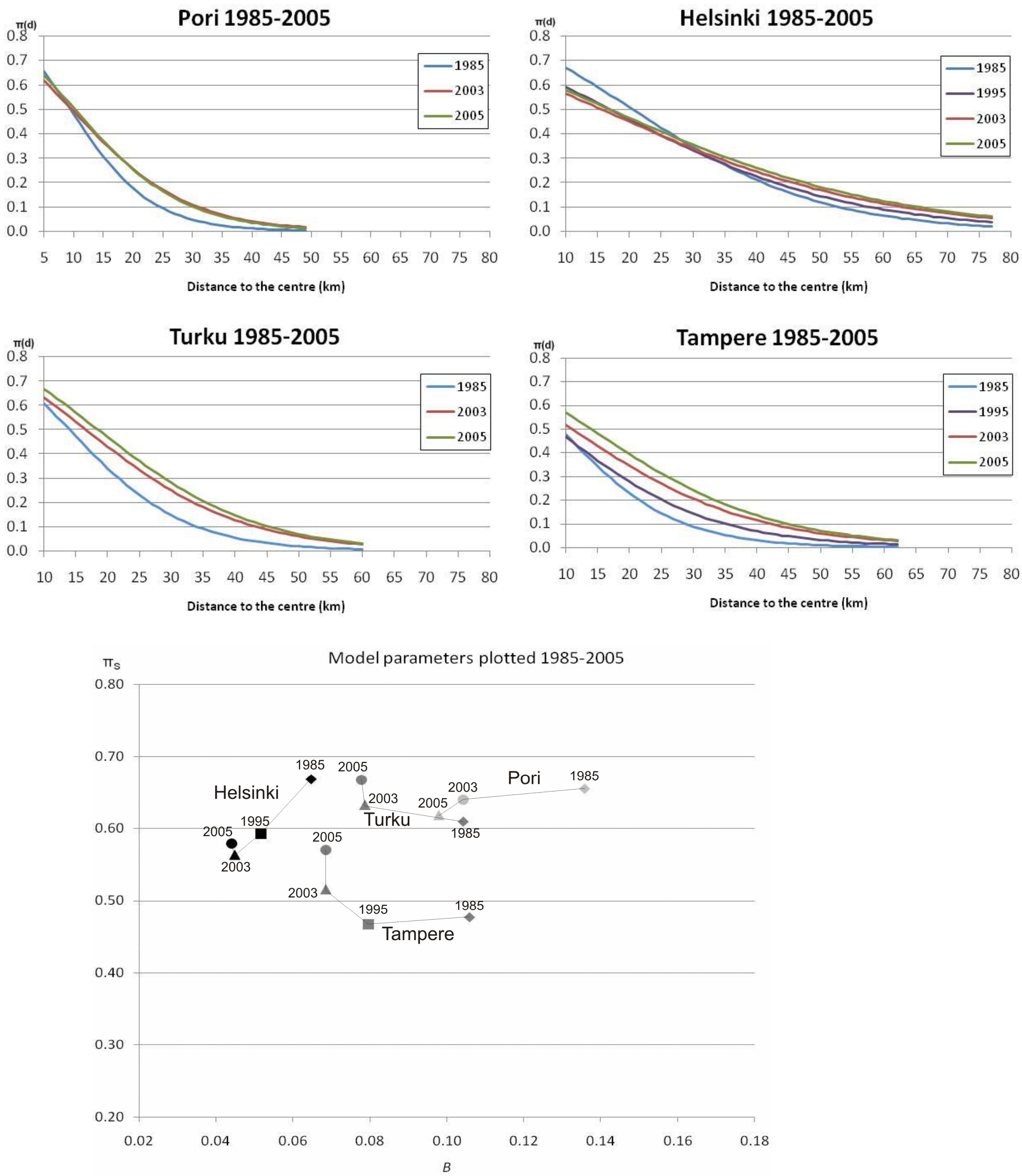


Figure 8. Temporal change in Finnish test sites, years 1985, 2003 and 2005. In Helsinki and Tampere, figures for the year 1995 are also shown. The upper part presents change in the form of curves and the lower part in the form of parameter values.

In Copenhagen, the temporal change has been minor, as indicated by Figure 9. Only the years 1995, 2000 and 2005 are included in the change analysis, since there was a profound municipality reform in 2007, and data from 2008 is thus not fully comparable with these curves. There is a slight decrease in the value of parameter π_S from 1995 to 2000, but in 2005 the value is a little higher again. At distances greater than 20 km from the city centre, the 2005 curve runs slightly higher than the 2000 and 1995 curves, indicating the enlargement of the commuting area. However, in comparison to other test sites, the change has been minimal.

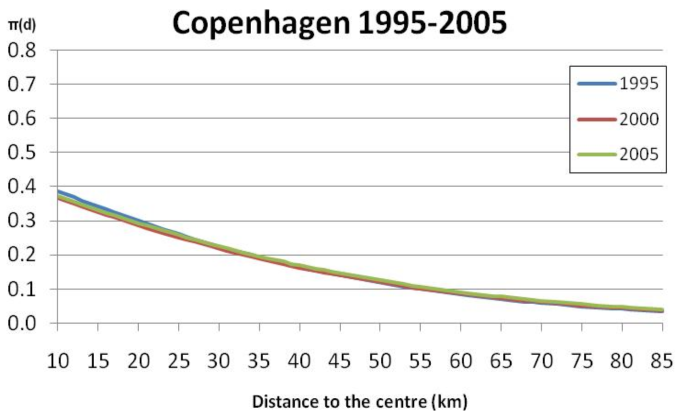


Figure 9. Changes in the commuting pattern of Copenhagen were minimal during the 1995-2005 period.

In Vienna, the curves show development during the 70s and 80s (Figure 10). The core area of the city increased its appeal during that period. The commuting area expanded, especially during the 1970s. This means that an increasing number of people are engaging in longer commuting trips.

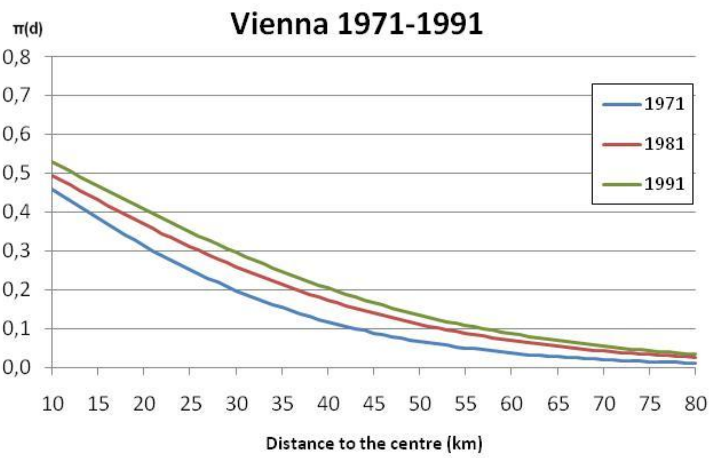


Figure 10. Changes in the commuting pattern of Vienna during 1971-1991. Commuting to the centre from the surroundings increased significantly during the period 1971-1991.

Urban development and changes in commuting patterns

Commuting is a result of location choices made by individuals and firms in terms of the housing and labour markets. Changes in the commuting gradient are responses to several dynamics occurring in the urban-rural continuum. Two evident dynamics influencing the curve parameters are changes in locations of work and population, i.e. centralisation versus sprawl, and changes in transport systems, i.e. accessibility. The factors behind individual level choices such as place of residence, job and travel mode form more complex interrelationships.

Figure 11 illustrates the framework developed for assessing the impacts of urbanisation trends on commuting patterns at a general level. The future development of major commuting patterns is interlinked with general urbanisation trends. In the figure, four corners (A-D) represent cases where the urban centre attracts commuters in a different way from surrounding area. The general urbanisation trend determines the location preferences of individuals and employment, which also changes commuting directions.

The framework illustrates some general trends, which are directly connected to commuting. Workplaces are either centralising or decentralising and commuting areas are either expanding or shrinking. The existing urban structure determines the number of major commuting directions.

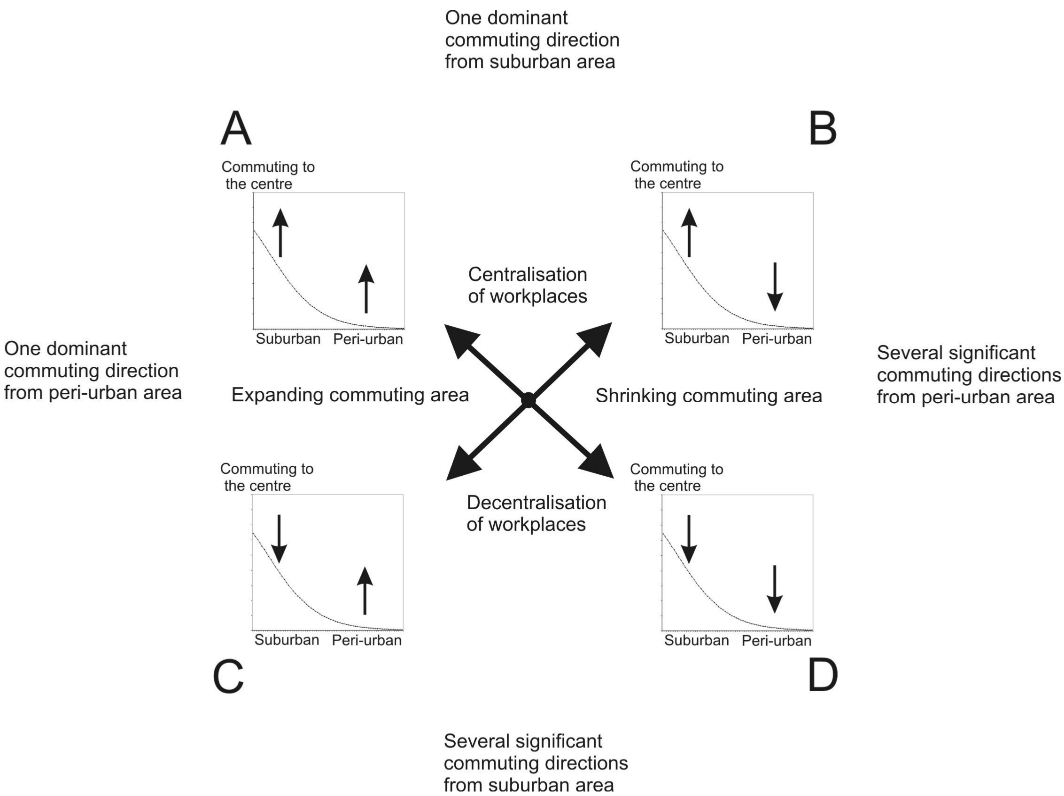


Figure 11. *Framework for analysing changes in commuting patterns oriented towards the urban centre from suburban and peri-urban areas. The changes presented in Figures 8-10 show different directions of development in the test sites. Corners (A-D) represent different commuting structures presented in Figure 6.*

Urban form patterns and location choices are the outcome of many forces. In the scenario framework (Ravez 2010) the main driving forces and implications for peri-urban development are considered for each scenario storyline. Here, the general trends of urbanisation patterns are linked to commuting. It is therefore expected that in various future scenarios, urban areas will have different commuting gradients. However, numerous other driving forces, which are not explained in the scenarios, may also alter future development.

The development of the transport and communication infrastructure is changing the way people are connected. Improved communication technologies have the potential to change traditional mobility patterns. People can work while travelling or work at home instead of commuting to the workplace. The implementation of information and communications technologies (ICT) is leading to more flexible ways of organising working practices. Increasing numbers of employees are now working in the information sector, which also creates the potential for telework since, technologically, work is no longer bound to a certain location (Helminen et al. 2007). Increased accessibility may promote long distance commuting from peri-urban to urban as well as between urban centres.

Telework has direct and indirect impacts on travel. Direct impacts are expected in the form of reduced commuting kilometres (Choo et al. 2002, Lyons et al.1997, Mokhtarian 1998), whereas indirect impacts include the consequences for total travel and travel behaviour as well as potential long-term effects on household location and land use (Lund & Mokhtarian 1994, Nilles 1991). In the Finnish study measuring the level of telework at 2001, the impact of telework on commuting was marginal, but ten years later the situation may be different (Helminen et al. 2007).

Commuting trends in Leipzig

Since Leipzig is one of the case study regions of PLUREL, it was given special attention in our analysis. As a result, an analysis was performed both for the Leipzig administrative district (municipalities mainly East of Leipzig) and for a self-defined area, a circle with 45 km radius around Leipzig city centre (here called the "Leipzig region"). Changes in commuting patterns were assessed based on data from 2000 and 2008. Between these years, there have been several changes in the municipality structure: in 2000, the Leipzig region contained 342 municipalities but in 2008 the number of municipalities was only 264. In the case of the Leipzig administrative district, the respective numbers were 89 and 80. These changes led to some uncertainty in the results, which will be discussed later.

In order to facilitate the interpretation of the curves, the empirical data is first presented in the form of maps (figures 12 and 13; Leipzig region and Leipzig administrative district respectively). The shade of grey in each municipality reflects the percentage of employees commuting to the core area: the darker the shade of grey, the greater the percentage. The commuter statistics were subject to certain privacy rules; if the number of commuters commuting to a certain municipality was smaller than 10, it was not presented at all. In the maps, these "no data" municipalities are marked in white. This leads to some uncertainty in the analysis: the probability of commuting to the core area may actually be fairly large in these municipalities, if the total number of employees is small. So, due to the small municipality size, this may be a statistical fallacy. In order to reduce the level of uncertainty, the number of employees in these "no data" municipalities was set at 0, and these municipalities were therefore not taken into account in the analysis.

The enlargement of the commuting area is clearly visible when comparing the maps: the darker shades of grey reach much further off in the lower maps, representing the situation in 2008. The same trend can also be seen in the absolute number of commuters, represented as black lines. Thicker lines, representing larger absolute numbers, are more common in the 2008 map than in the 2000 map.

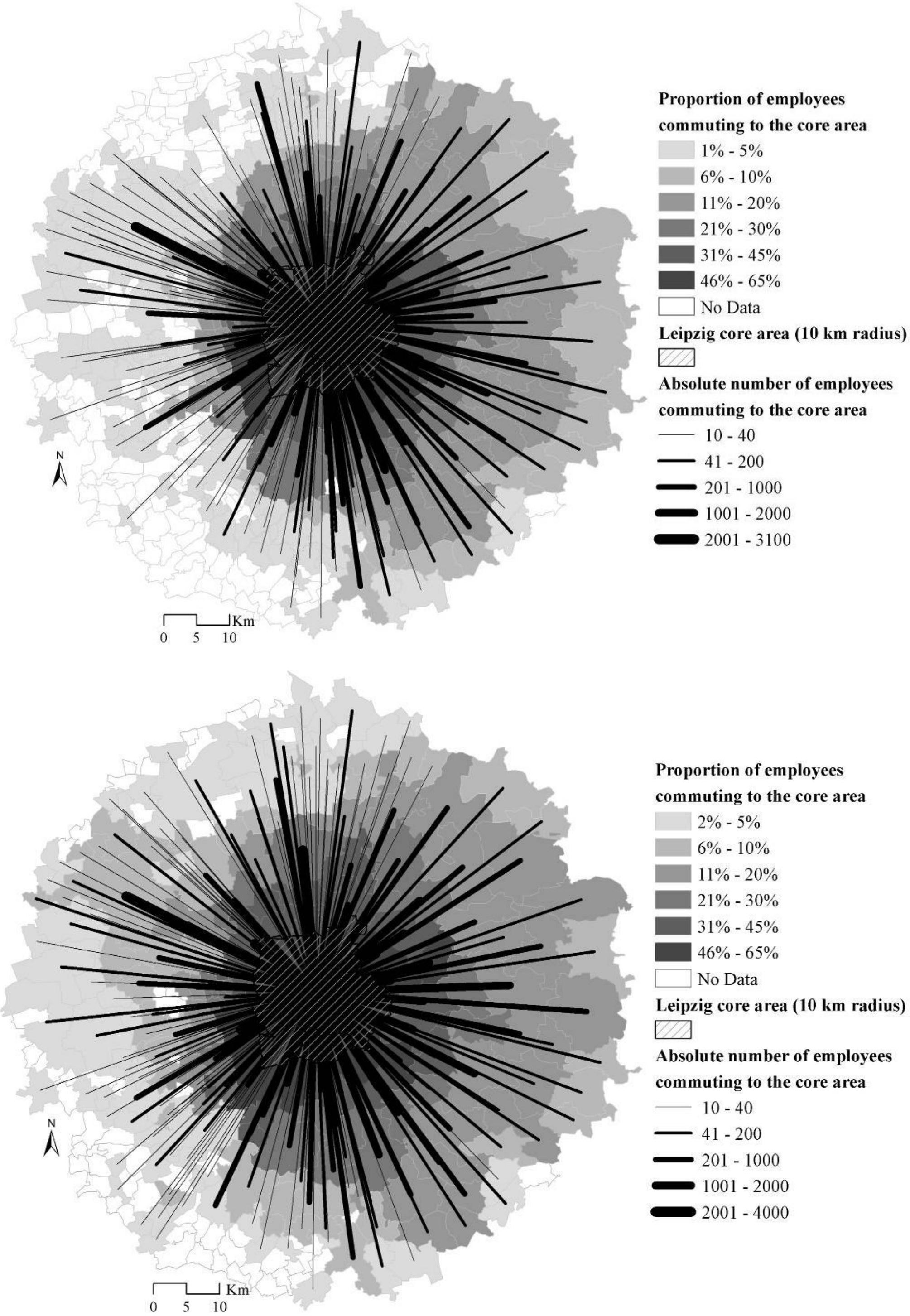
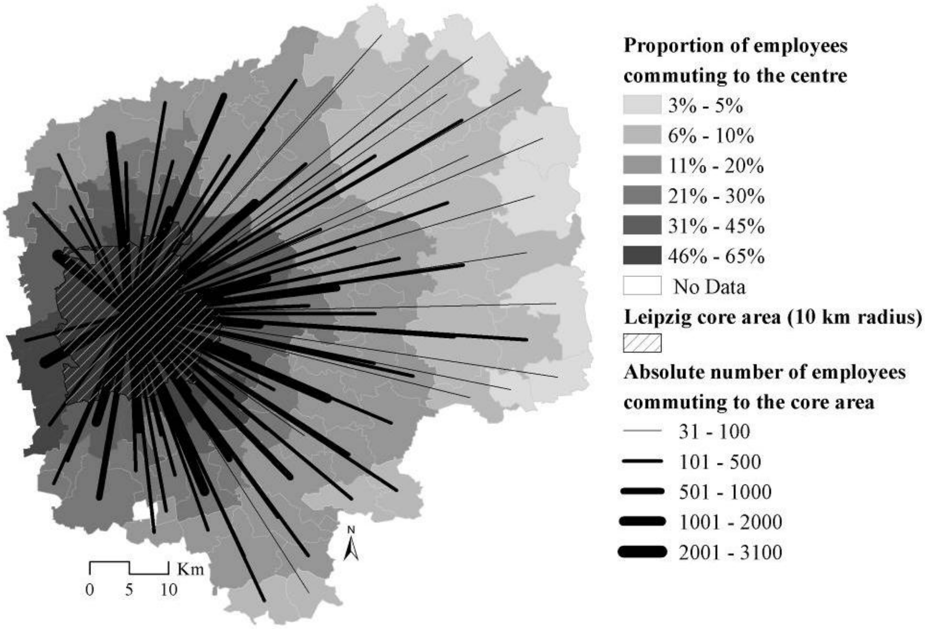


Figure 12. Commuting statistics for Leipzig region as maps. The upper map represents the situation in 2000 and the lower map that in 2008. The percentage of employees commuting to the core area is presented in different shades of grey and the absolute numbers of employees commuting to the core areas as black lines, the width of the line being proportional to the number of employees.



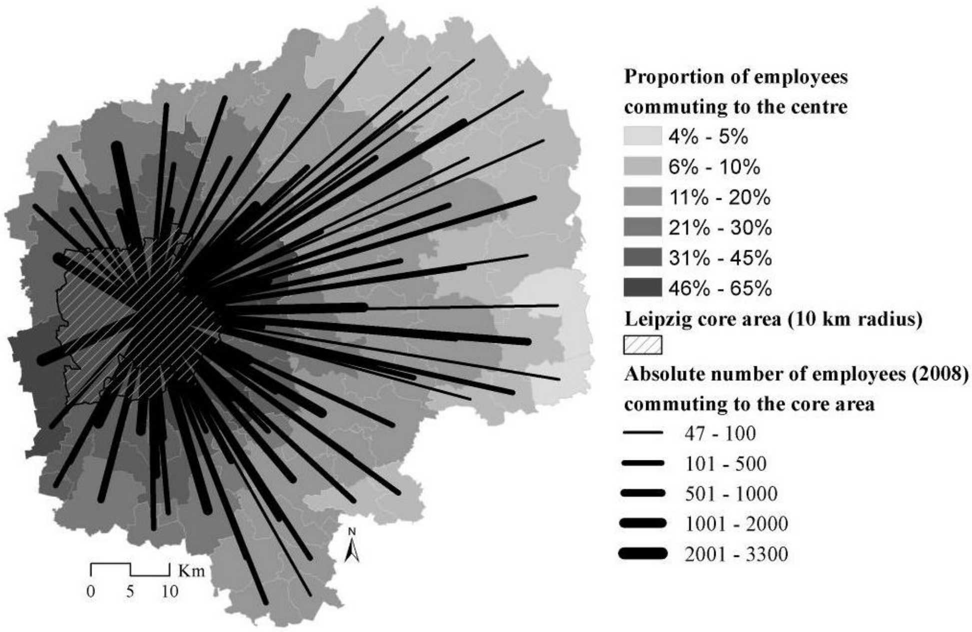


Figure 13. Commuting statistics for Leipzig administrative district as maps. The upper map represents the situation in 2000 and the lower map that in 2008. The percentage of employees commuting to the core area is presented as different shades of grey and the absolute numbers of employees commuting to the core areas as black lines, the width of the line being proportional to the number of employees.

The same trend is also visible in the modelled curves (Figure 14). In the curves, however, the differences between study areas become clearer. When commuting patterns are analysed in the Leipzig administrative district (curves on the left side, Fig. 14), the appeal of the core seems to be much stronger than when the patterns are analysed in the context of the Leipzig region (curves on the right side, Fig. 14). The 10% boundary in probability is reached between distances 37-41 km in the case of the administrative district, whereas the respective distances are 28-30 km in the regional analysis.

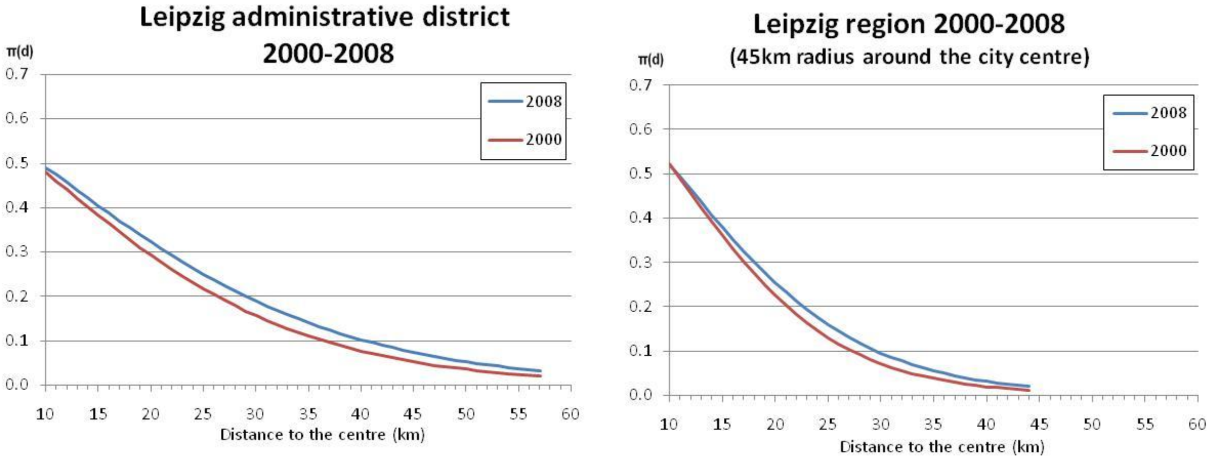


Figure 14. Temporal change in commuting curves. Left: Leipzig administrative district. Right: Leipzig region. Statistics from the years 2000 and 2008.

The changing pattern was also visualised as dots (Figures 15 and 16, Leipzig region and Leipzig administrative district respectively). Here, the number of employees and the proportions commuting to the core area were compared based on the 2008 municipality borders. This means that data from 2000 was aggregated on a new level. This causes some distortions in the analysis. In some municipalities, where it seems that the proportion has grown a great deal, the reason may be as follows: in 2000 the absolute number of employees commuting to the core was less than 10 in many municipalities and thus not represented in the statistics. By 2008, several of the municipalities that were independent in 2000 had unified, thus making these small numbers of commuters visible after being combined.

An interesting detail is that commuting occurring inside the core area seems to have decreased; the core area municipalities (Leipzig and Markkleeberg) and the municipalities next to those have blue dots. This indicates a change in employment location: there are new workplaces in the neighbouring municipalities that do not fall into the category of "core area", and thus, some of the movement that previously occurred within the defined core area is now directed towards the neighbouring municipalities.

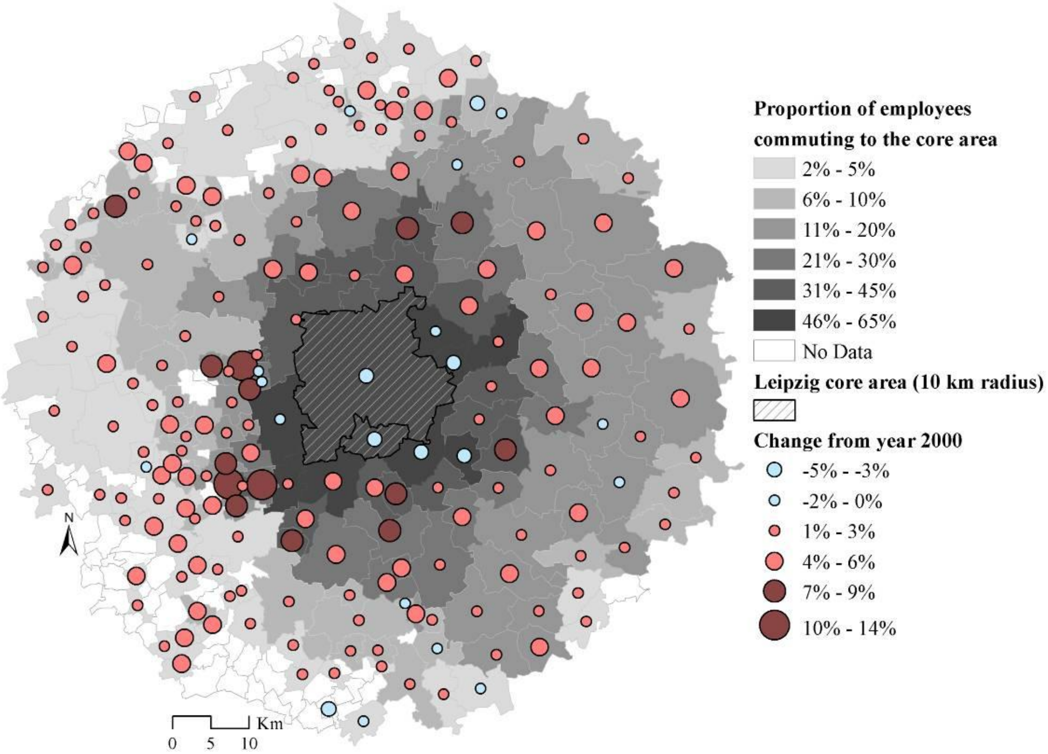


Figure 15. Changes in the proportion of employees commuting to the core area in the Leipzig region. The situation for 2008 is presented in different shades of grey, whereas the change from year 2000 to 2008 is represented as dots, red ones indicating growth and blue ones a decrease.

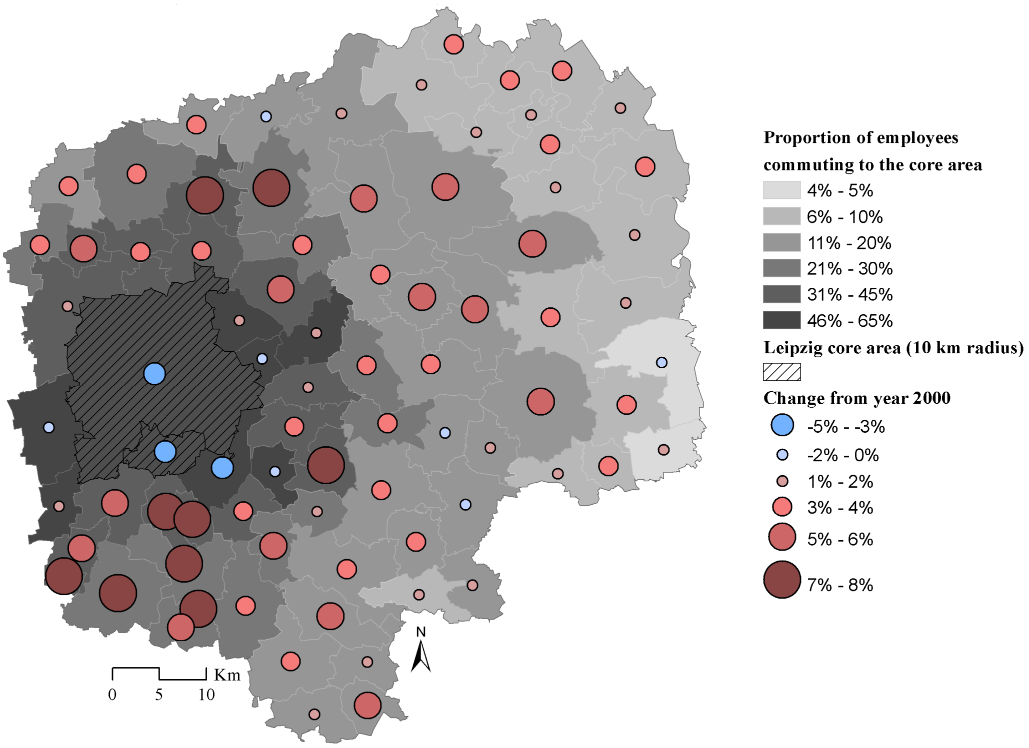


Figure 16. Changes in proportion of employees commuting to the core area in Leipzig region. The situation for 2008 is presented in different shades of grey, whereas the change from 2000 to 2008 is represented as dots, red ones indicating growth and blue ones a decrease.

Discussion

The construction of a response function concentrated on the link between urban structure and commuting. This means that individual-level socio-economic factors such as education, occupation, age or gender were not considered here separately, although they certainly do influence travel patterns. The variation of interconnected socio-economic factors may explain the travel patterns of a region in more detail than structural elements, but the inclusion of several different factors in the model also creates difficulties in separating one effect from another. In addition, the response function serves as a generic model, which does not explain variation at a more detailed level. The model does not explain the complex travel patterns in urban regions, since it concentrates only on a narrow slice of total travel. However, comparing the cases illustrates how the monocentric model fits contemporary urban regions in the case of commuting.

In general, the curves corresponded rather well to the expectations we had beforehand. Large commuting areas are typical of large monocentric cities with a fast transport system (Newman and Kenworthy 1996). In this study, the study areas with low parameter *B* values were exactly such cases. Improvements in accessibility usually lead to travelling longer distances (Kenworthy and Laube 2002), which was visible in our results. It is typical of polycentric urban regions, that a significant proportion of commuting trips are not traditional suburban-to-centre trips (Aguilera 2005). This was apparent in our results from the UK cities with low π_S values but high *B* values.

The RUR typology has been applied at NUT3 level, which is a rather coarse level for analysing intra-regional issues (see Loibl et al. 2008). In the case of the commuting gradient, the typology seems to be reasonably usable. However, the typology has only one class for urban polycentric regions. In reality, there are several types of urban structure, which are somewhere between a monocentric and polycentric structure. Champion (2001) identifies at least two versions of polycentric configuration: 1) an individual metropolitan area including suburbs and commuting hinterland and 2) a region containing a number of cities, none of which is dominant.

In the case of monocentric regions, the phase of the decentralisation process varies and, depending on the spatial scale polycentric structure, may emerge at different stages of development. These different stages of development may not be visible in a generic RUR typology. It is expected that in some cases commuting gradients will not fit with the typology due to the different phases of the decentralisation process, especially in an RUR-class *very large monocentric*. For example, in London and Copenhagen commuting curves indicated the decentralisation of workplaces. Also, polycentric regions range from polynucleated urban regions to twin cities. The Manchester-Liverpool region is more clearly part of a polynucleated urban region, whereas Leipzig-Halle is more of a twin city.

In addition, geography has a huge impact on urban form and commuting patterns; coasts and mountains shape the urban form, making each urban area unique. A generic response function cannot take account of all of these local conditions. The interpretation of the curves requires sound knowledge of local circumstances. For example, the location of smaller employment concentrations and the status of the transport system are vital pieces of information when interpreting and explaining the curves.

Methodological considerations

Definition of the centre

As mentioned before, our definition of an urban centre does not take account of the physical size or any other properties of the urban agglomeration in question. This makes the comparison of different cities possible, but it also has certain effects on the results. A good example is provided by the case of Copenhagen. Based on previous studies (e.g. Nielsen and Hovgesen 2005) the commuting gradient of Copenhagen was expected to be quite similar to that of Helsinki, since both of these cities are strongly monocentric in character. However, the parameter π_S received a significantly lower value in the case of Copenhagen than in the case of Helsinki, which means that the probability of commuting to the core area from the close areas is much lower in Copenhagen than in Helsinki. In our analysis, the core area included the municipalities of Copenhagen and Fredriksberg, because these municipalities had their centroid within the 10 km radius circle around Copenhagen's functional midpoint. Nielsen and Hovgesen (2005) define the urban core differently: in their study the core comprises not only Copenhagen and Fredriksberg, but also the former county of Copenhagen, which consists of 18 additional municipalities. Clearly, such a difference in the definition has effects on the results.

Different units of analysis led to different results

In order to assess the effects of different units of analysis, the Helsinki data was analysed using various levels of aggregation. The differences in the model parameters were fairly significant, as shown by the diagram in Figure 17. More detailed data (grid cells) gave higher values for both parameters.

As proven by our tests in the Helsinki region, different levels of aggregation in the commuter statistics have a corresponding effect on the results; the less aggregated the data, the more reliable the results. If the statistical information is aggregated on a very coarse level, the distance information becomes sporadic. For example, if the municipalities are used as units of analysis, the size and shape of the municipality has profound effects on the distance information used for the analysis. In the case of large municipalities in particular, the use of functional midpoints for each municipality (if such data were available) would be highly recommended in order to make the analysis more reliable.

Changes in municipality borders are common nowadays. These changes are problematic in this sort of study, because they change the level of aggregation and the distance information forming the basis of the analysis. Due to this, special attention should be paid to the comparison of datasets from different years, in order to assess the reliability of the results.

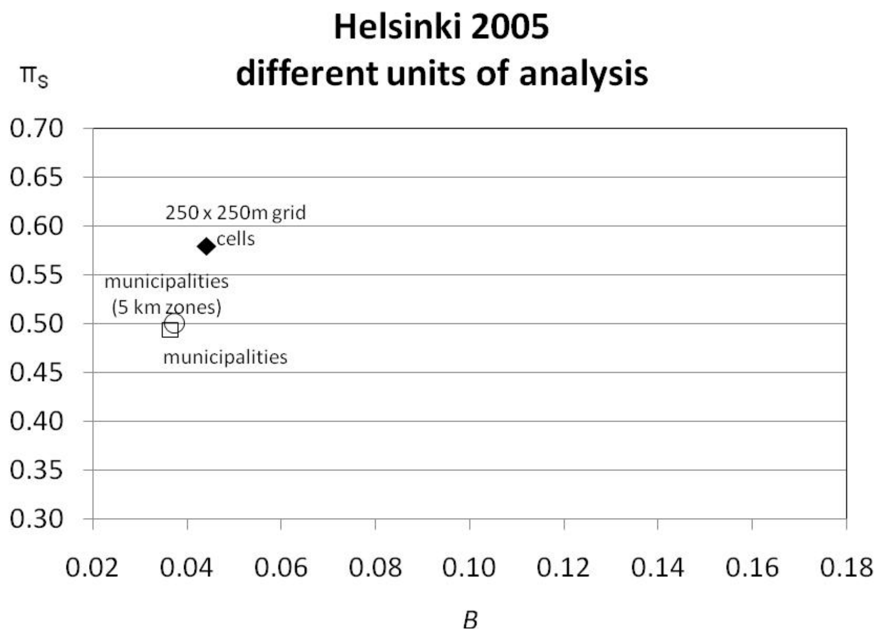


Figure 17. Model parameters resulting from analysis of datasets of different levels of aggregation.

Conclusions

In rural-to-urban regions, commuting reflects the interaction between urban and peri-urban areas. The aim of the response function of commuting was to gain aggregate results regarding in-commuting to city centres in several regions of different types. The outputs of the response function were derived from the probability gradients modelled for the test sites, based on empirical data. These gradients were aggregated into archetypal commuting curves for different types of regions. The gradients determine the extent of the functional commuting areas of cities and indicate the level of centralisation of workplaces.

Changes in the urban structure are particularly clear at the periphery of the cities. New patterns of settlement and employment require new patterns of mobility and transport. In peri-urban areas, distances tend to be longer, with more complex flow networks. In order to achieve sustainable growth in urban areas, the entire functional urban region must be considered as well as links between urban regions. To see the relationships between the land-use functions and commuting we must examine monocentric and polycentric structures separately.

In monocentric regions, the interaction between the urban core and peri-urban is strong. In a monocentric structure, the major direction of commuting flows is towards the core. The concentration of jobs in one core supports radial transport systems and enables an adequate public transport system, at least through main transport corridors. Fast radial transport systems tend to enlarge commuting areas and increase commuting distances.

Simultaneous urban growth and a lack of sub-centres in monocentric structures tend to boost undirected settlement dispersion i.e. urban sprawl. Urban sprawl enlarges the functional regions of commuting and increases the population, especially in car-dependent areas with low densities and a fragmented structure. Peri-urban public transport systems are usually not sufficiently well-established to prevent car-dependency.

So called co-location hypothesis supports the mixed land use of residences and workplaces as a solution to increasing commuting distances (Giuliano & Amall 1993, Næss 2007). However, it is questionable how well the co-location of jobs and housing works in a situation where there is a high level of mobility and both work and workers are highly specialised. As the general mobility level becomes higher, people are less likely to prefer local jobs to more distant ones if distant jobs are otherwise attractive (Næss 2007). In particular, educated workforce seeks job opportunities from specialised employment markets which attract employees from the regional catchment area. Work requiring special skills and a high level of education tends to favour central locations.

As urban sprawl proceeds, the decentralisation of employment and workplaces follows the dispersion pattern of settlement. This means that destinations disperse in addition to the dispersion of the origins of the commuting trips. However, workplace suburbanisation usually means a shift of employment from the highly priced and congested centre to areas with good accessibility by car. As workers become more car dependent, workplaces are located in order to be better accessible by car. The dispersion of settlement and suburbanisation of workplaces increases the variation in both the origins and destinations of commuting trips, but decreases the options of modal choice.

In a polycentric urban structure, employment is concentrated in several nodes. On the one hand this means that workers in the urban region have a shorter average distance to the closest centre. In theory, this should decrease commuting distances. On the other hand, the distribution of work across several nodes also means more alternatives for the work trip destination. These alternatives are available through the transport system, which takes the form of a network. The commuting patterns of a polycentric region are more complex than those of a monocentric structure. Commuting takes place between the main cores of a region as well as between sub-centres. A sustainable polycentric structure requires a well-developed public transport system capable of transferring commuters from various origins to various destinations.

In a polycentric structure, it is expected that the location of cities, subcentres and infrastructure as well as the size and shape of urban development will be reflected in major commuting flows. The morphology of the urban region i.e. how nodes are located and linked to each other, determines how well the structure works in the case of commuting. For example, if a polycentric structure consists of a ribbon of dense nodes connected by a railway, most commuting between the nodes can be handled using public transport. In other cases, a fragmented network of urban cores and sub-centres may lead to a situation where the greatest accessibility between nodes is by car.

The output of the response function helps in estimating the extent of functional commuting areas around cities and the level of centralisation of workplaces in different rural-urban structures. The directions of major commuting flows depend on the alternatives. In a pure monocentric model, the only alternative is commuting to the centre. As monocentric cities grow, commuting distances tend to increase, with very long commuting trips in particular becoming more common. This strong traditional commuting pattern is challenged by the decentralisation of workplaces.

As a result of decentralisation and dispersion processes, commuter flows traditionally oriented towards the urban core are changing into criss-cross patterns. In a monocentric structure, the decentralisation of workplaces may even boost the expansion of commuting areas as workplaces become more accessible by car.

In polycentric regions, the main cores have rather limited commuting areas. The distance to the core does not explain commuting distances. Peri-urban areas are situated in-between urban centres on the fringe of adjacent commuting areas. Peri-urban public transport system development depends on the size and densities of peri-urban sub-centres. The concentration of activities in peri-urban sub-centres also enables transport modes of greater sustainability.

The analysis of response functions should be further linked with different transport systems. A monocentric urban form is an easier target for public transport planning, whereas a dispersed form, in general, enforces car-dependency. On the other hand, a polycentric structure may, in theory, minimise commuting costs by shrinking the distance between the settlement and employment. However, a sustainable polycentric urban structure requires a public transport network that can manage criss-cross-commuting between several centres. At individual level, several factors besides commuting cost usually influence people's location or travel mode choices (Giuliano & Small 1993).

The changes in the commuting gradient presented here are responses to several dynamics occurring in the urban-rural continuum. Two evident dynamics influencing the curve parameters are changes in locations of work and population, i.e. centralisation versus sprawl, and changes in transport systems, i.e. accessibility. The factors behind individual level choices, such as place of residence, job and travel mode form complex interrelationships. At aggregate level, these choices are controlled by supply and demand in the housing, labour, transport and land markets (Jansen, 1993). To analyse these relationships and their influence on commuting, we would need a more detailed analysis.

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