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Effects of municipal boundaries measured by combining urban scaling and spatial interaction

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Urban scaling, the superlinear increase of socio-economic measures with increasing population, is a well-researched phenomenon. This article is focused on socio-economic performance scaling, which could possibly be driven by increasing returns of the size and density of interaction networks. If this is indeed the case, we should also find that spatial barriers to interaction affect scaling and cause local performance deviations. Possible barring effects of municipal boundaries are important from the perspective of urban and regional governance. We test the hypothesis of barring effects by correlating municipal boundaries with the structure of commuter networks within a large densely urbanized region, the Randstad in The Netherlands. The measured impacts of these boundaries are correlated with local employment-scaling deviations. Applying spatially weighted modelling techniques, we find that municipal borders have significant effects on inter-municipal commuting and indicate these effects on the map. The results show particularly significant correlations along dividing lines between large urban agglomerations and rural communities. The southern part of the Randstad is more fragmented by such dividing lines than the northern part, which could partly explain the diverging economic development between the two parts.

1. Introduction: municipal boundaries and governance fragmentation

Municipal boundaries represent, as it were, the governance fragmentation within regions and, particularly, in urban agglomerations. Undoubtedly, the independent municipalities have socio-economic connections. However, the question is whether this multi-governance structure within compact urban agglomerations has a strong cohesiveness and synergy resulting in an optimal social, economic and cultural coherence. In a recent OECD report on urban governance [1], the authors state that the effects of governance fragmentation in urban agglomerations are hardly discussed in the existing urban science literature. And this is despite the fact that the influence of governance structures on the socio-economic performance of cities is pervasive and inducing a high degree of coordination complexity and lack of governance cohesion [1–4]. Thus, governance fragmentation may seriously hamper the enhancement of socio-economic strength in an urban agglomeration. In particular, fragmented urban agglomeration governance can obstruct necessary transport infrastructure investments, effective land use planning [2] as well as business and environmental regulation. These problems impede socio-economic growth [3,4], whereas the more closely governance and functional boundaries within an urban area correspond, the more likely it will be that effective local growth promotion policies develop [5]. The OECD authors [1] find that cities with fragmented urban governance structures tend to have lower levels of productivity. For a given population size, an urban area with twice the number of municipalities is associated with around six per cent lower productivity. The authors even call this a 'fragmentation penalty'.

With this paper, we aim to contribute to the investigation of the socio-economic effects of governance structures by using the urban scaling methodology to find locations of economic underperformance and then use a spatial interaction model to find explanations in terms of municipal boundaries. We take the western part of The Netherlands, the Randstad, as our research area. The hypothesis investigated is that municipal fragmentation of urban agglomerations within the Randstad could hamper economic interaction between locations, with a detrimental effect on local and regional employment. We use commuter flows as an indicator of inter-local interaction and investigate to what degree municipal boundaries bias efficient flow patterns resulting from the geographical distribution of work and home locations, travel modes and travel time propensities of the working population. Subsequently, we correlate these biases with local employment deviations from the employment-scaling line found for the entire Randstad. Methodologically, the investigation necessitates analysis of dependent and explanatory variables at a much more detailed geographical (micro-)level than the municipal (macro-)level at which urban scaling studies are often done.

The structure of this paper is as follows. In §2, we discuss urban scaling at the macro-level followed by our approach to analyse micro-level scaling. Next, we compare our empirical findings at the micro-level with those at the macro-level. Section 3 addresses a cornerstone of the study, the effect of municipal borders on daily commuting patterns. With this we answer the question as to where municipal borders hamper commuting and efficient functioning of the labour market. Subsequently, local border effects are correlated in their turn with local employment residuals of the micro-level scaling. We conclude our paper in §4 with a discussion of the policy-relevant consequences of our investigations.

2. Urban scaling: macro-level compared with micro-level

2.1. Urban scaling and spatial interaction

Urban scaling is a broad field of research including several types of scaling such as fractal structures in city growth [6], Zipf distributions of the size of cities [7,8] and allometric scaling. In this paper, we focus on allometric scaling, i.e. the study of the relation between size of a specific entity (e.g. city) as independent variable and city characteristics such as gross urban product (GUP), employment in terms of number of jobs, number of crimes and total road length as dependent variables [9–13]. This *urban scaling* relation is described by a power law dependence of, for instance, the GUP on population size:

$$G(N) = aN^{\beta}, \tag{2.1}$$

where G is the GUP[1] and N the population size of a city. The exponent β and the coefficient a follow from the measurement through regression analysis; in most cases, values of the exponent are between 1.10 and 1.20. Other units of analysis are cities defined as municipalities and larger urban regions [14–17]. For instance, recently van Raan [15] discussed the superlinear increase of the GUP, productivity and employment with an increasing population of municipalities and regions in Germany, Denmark and The Netherlands. The GUP scaling exponent in The Netherlands is around 1.15 which means that a city twice as large (in population) as another city can be expected to have approximately a $2^{1.15} = 2.22$ larger socio-economic performance (in terms of the GUP).

Urban scaling also includes linear and sublinear behaviour. For instance, in [9], it is found that road surface and other material infrastructural facilities typically scale sublinearly. Scaling characteristics may depend on the definition of urban areas in terms of population size and population density, and even on the size of a city measured in terms of residents and of working population size [18]. Therefore, linear scaling can be found [19,20] in situations where other researchers find superlinear scaling [13]. Different definitions of cities can even lead to changing the scaling exponent from superlinear to sublinear as is found for transport-related CO_2 emissions in US cities [21]. Scaling exponents may also differ for the chosen sets of cities [15,16,22], for example for cities in the richer western part of the EU as compared with cities in the eastern part of the EU [23], and scaling exponents may vary in time [16,18,23–25]. Scaling exponents differ for the various variables such as for instance gross domestic product, employment and patents [26]. In [27], it is shown that the economic structure of cities may considerably affect the measured urban scaling exponents.

Even within a within a broader variable such as income scaling exponents may differ: an Australian study [28,29] shows that for lower income the scaling is about linear but for high income the scaling is superlinear. An overview of scaling characteristics in different situations, particularly the sensitivity of urban scaling laws to city definitions, is given in [30–32]. In [33], it is shown that the estimation of scaling exponents is a challenging problem, for instance because of heavy tails in city population distributions or large fluctuations of the dependent variables. Nevertheless, an extensive recent study of urban scaling in Brazil [34] using a large number of variables and different statistical approaches with, for instance, population density cut-offs clearly shows that socio-economic variables (e.g. GUP) scale superlinearly with city population size, infrastructural variables (e.g. length of street network) scale sublinearly and individual basic services (e.g. number of houses) scale linearly.

According to a widely held hypothesis in the model-oriented literature [35], the scaling of urban economic performance is driven by innovation-inducing social and economic interactions that increase disproportionally with urban population size. For instance, in [6], an approach is discussed in which urban scaling is explained based on the distant-dependent interaction range between the citizens and on the spatial structure, in particular fractal properties of the cities. In a recent paper, Altmann [36] presents models that take the effect of interactions between individuals in different cities into account. Results show that including inter-city spatial interactions leads to better models and a change in the scaling.

Interactions that induce socio-economic growth are known among economists and economic geographers as 'Marshallian externalities' and 'Jacobs externalities' [37]. Other, and additional, explanations for urban scaling are provided by urban hierarchy and central places theory, and market gravitation [38,39]. In any of these explanations, face-to-face interactions are at centre stage. We thus would expect that local physical, socio-cultural and administrative interaction barriers diminish urban performance scaling or, in other words, that these barriers induce negative local performance residuals of the general scaling model. In this study, we investigate the role of municipal boundaries in this regard.

To find effects of boundaries on inter-local interaction and economic performance scaling, the spatial units for measurement should be more detailed than the areas enclosed by these boundaries. Therefore, in this study, we go into further detail and investigate how scaling works at the micro-level of local neighbourhoods, how this micro-scaling relates to macro-scaling and how micro-scaling can reveal the effects of municipal boundaries on interaction and economic performance. Do adjacent neighbourhoods divided by municipal borders show less interaction and more negative scaling residuals than adjacent neighbourhoods within municipalities, controlling for other explanatory variables, notably social and economic composition, and travel distance? The study focuses in this respect on inter-local interaction by way of spatial commuting patterns, whereby local and urban employment is taken as a dependent variable.

Investigating micro-scaling however requires another approach as compared to the macro-level in which urban agglomerations, municipalities or regions are the unit of measurement. The reason is that at the local level, clusters of economic activity such as ports, airports, manufactural sites, business parks, offices and shopping centres are often spatially separated from population neighbourhoods. This renders a direct scaling model senseless at the geographical micro-level. Only some fraction of the population living in a specific neighbourhood will depend on the economy in that neighbourhood; many people will commute to other areas in the wider environment. The essence of the urban scaling phenomenon is the actual spatial interaction field: the market area for contacts, exchanges of labour, exchange of ideas, etc. In theory and practice, it is therefore the spatially extended *daily urban system* that acts as the basis for the scaling mechanism. A model for urban scaling at the micro-level has to take this into account. In this study, we therefore apply a spatial gravity function to micro-location employment data [40]. Micro-locations are the around 1500 four-digit postal code areas[2] in the Randstad, the densely populated western part of The Netherlands with around seven million inhabitants, consisting of 92 municipalities among which are the four largest cities in the country.

2.2. Macro-level data: municipalities

A recently published study [15] discusses the scaling of municipalities in Germany, Denmark and The Netherlands, with GUP (municipal) as the main variable.[3] Data on employment and productivity are also available in that macro-level study. Given our focus on the most densely populated part of The Netherlands, the Randstad, we use these data to analyse the urban scaling in this region. In our macro-level approach, we define the Randstad as the province of South-Holland (including the urban agglomerations of Rotterdam, The Hague, Leiden and Dordrecht), plus the urban agglomerations of Amsterdam, Utrecht and Haarlem, in total about 7 million inhabitants in 92 municipalities. In figure 1, we

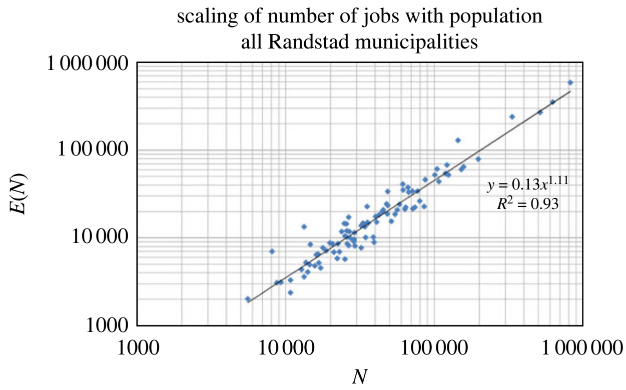

Figure 1. Scaling of employment $E(N)$ for all municipalities in the Randstad, 2014–2016. N: number of inhabitants.

show the scaling of employment $E(N)$ in terms of the number of jobs for all Randstad municipalities. The scaling exponent is 1.11 (95% CI 1.09–1.13, $R^2 = 0.93$). Next to the scaling exponent, the deviations of the individual municipalities from the regression line are important. These scaling *residuals* are a measure of the difference between the actual employment of a municipality and the expected value based on the scaling exponent determined by the entire set. For the calculation of residuals, we refer to [14]. We present the residuals of all Randstad municipalities in the electronic supplementary material, table S1. If we look at the four largest cities (in order of population size: Amsterdam, Rotterdam, The Hague and Utrecht), we see the better position of Amsterdam and Utrecht as compared to Rotterdam and The Hague.

In electronic supplementary material, table S1 (and also clearly visible in figure 1), we see outliers, particularly municipalities with an exceptionally high residual. We take two examples at the low end (left side) of the population scale. Ouder-Amstel is a small Amsterdam suburb (population about 14 000), but it is the location of a large international bus station (Eurolines) combined with a major Amsterdam railway station with together about 4 million passengers per year. This clearly provides Ouder-Amstel many more jobs than a municipality of similar size. The second example is Zoeterwoude, a small Leiden suburb of around 9000 inhabitants. This municipality is home to the large Heineken beer factory which gives this municipality thousands of jobs more than can be expected on the basis of its size. At the high end (right side) of the population scale, we also see an outlier: Haarlemmermeer, a major Amsterdam suburb of about 150 000 inhabitants. The high positive residual of Haarlemmermeer can be explained very well: Amsterdam International Airport Schiphol, the fourth largest airport in Europe, is located in the municipality of Haarlemmermeer.

2.3. Micro-level data: postal code areas

There are no data on productivity and GUP/municipal product available at the micro-level of postal code areas. But we do have reliable data on employment and population at this level. This enables comparison with the findings at the macro-level. Thus, we take local employment as the dependent variable and population as the explanatory variable.[4] Units of measurement for the micro-scaling model are 1500 postal code areas in the Randstad region.

Scaling emerges from networked interactions between social and economic actors and population. This means that analysis at the micro-level must be based on the spatial fields within which these interactions occur. Therefore, instead of just taking into account the local employment and population in a specific postal code, we use a spatially weighted average version of each variable to take into account the wider market system in which each postcode is embedded. This spatially weighted average of nearby employment and population in each postal code is calculated by using a linear and negative (car) travel time decay function with a cut-off at 45 min travel time. The actual employment and population variables are thus transformed into market potential variables that account for both the centrality of locations within the surrounding market field as well as the size of this surrounding market field (the 'daily urban system' within 45 min travel distance, by car).

Based on the municipal urban scaling model described in the previous section and similar to equation (2.1), we analyse the following relationship for employment at the micro-scale:

$$E_w(N_w) = a_w N^{\beta_w}, \tag{2.2}$$

where E_w is the spatially weighted average employment around a postal code and N_w is the spatially weighted population around this postal code. The coefficient a_w and the exponent β_w follow from the measurement through a Poisson linear regression with a log-link function. Similar to the macro-level perspective, we find a scaling exponent (β_w) of 1.12 (99% CI 1.11–1.12, $R^2 = 0.98$), and this value lies within the range that is often found in scaling studies.

In the previous section, we discussed the importance of residuals of individual units next to the scaling exponent. The employment-scaling residuals in our micro-level approach are a measure of the difference between the actual (spatially averaged) employment of a postal code area and the expected value based on the scaling exponent which is determined by the entire set of postal code areas within the Randstad. These postal code area residuals can be mapped with GIS. The results of the residuals analysis are presented in figure 2. Negative employment residuals are indicated in orange and positive residuals in blue, so that spatial patterns are easily discernable.

The map of residuals shows a clear pattern. The north-eastern part of the Randstad region, known as the *North Wing* with Amsterdam and Utrecht as core cities, is dominated by areas with positive employment residuals. The southwestern part with the core cities Rotterdam and The Hague is dominated by negative residuals. The Rotterdam Port Area is one of the few exceptions in this general pattern. This economic lagging of the South Wing vis-à-vis the North Wing is a well-known fact in The Netherlands.

The scaling exponent in this micro-analysis of 1.12 for the Randstad lies well within the confidence interval of the scaling exponent 1.11 measured with the macro-level data for the Randstad discussed in the previous section. We see that the difference between the macro-level scaling exponent based on entire municipalities and the micro-scaling exponent of postal code areas within the same region is negligible. It is clear that micro-scaling based on spatially averaged postal code areas and macro-scaling based on municipalities give comparable results.

3. Effects of municipal boundaries on micro-scaling residuals

3.1. First analytical step: effect of boundaries on commuting interaction

Inter-local interaction is a pivotal variable in our analysis: the hypothesis is that negative local employment-scaling residuals could be explained by the barring effect of municipal fragmentation on inter-local interaction. To test this, the analysis is done in two consecutive steps. First, we investigate with a spatial interaction model the *actual interactions* in terms of the daily flows of workers from residential areas of origin to work destination areas, again at the micro-level of postal code areas.[5] This enables us to detect barring effects of municipal boundaries. In the next step, we measure with a spatial regression model where, and to what degree, the boundary effects on interaction found in the first step explain the micro-level scaling residuals discussed in the previous section.

Mathematically, the basis is a spatial interaction model [40–42]:

$$T_{ij} = \kappa R_i^{\alpha} W_j^{\gamma} d_{ij}^{\beta}, \tag{3.1}$$

where T_{ij} is the estimated commuting between areas i and j; R_i represents the residential employed population in area i; W_j is the number of individual working places in area j; d_{ij} is the travel time (by car) between i and j; and κ, α, γ and β are the parameters to be estimated on the basis of the empirical origin–destination matrix. They describe the relationship between the spatial commuting flows and each of the explanatory variables. In this first step (equation (3.1)), we have not yet included a specific municipal boundary value. To estimate the exponents in this model with a Poisson regression, we use a log-linear specification as is commonly done in spatial interaction analysis (see [43,44] for an extensive discussion):

$$T_{ij} = \exp(\kappa + \alpha \log R_i + \gamma \log W_j + \beta \log d_{ij}). \tag{3.2}$$

When estimated, this initial 'base' model—without a municipal boundary variable—has an adjusted R^2 of 0.68. In figure 3, we present a map of the residuals, where less-than-expected actual commuter flows, i.e. negative residuals, are given as red lines; positive residuals are given as blue lines.

The map in figure 3 contains dense information from which a general pattern emerges. Blue lines, representing *more-than-expected* commuting (given the observed distribution of the working population, employment opportunities and travel time decay of individual commute propensities), are overrepresented *within* the large (Amsterdam, Rotterdam and The Hague) but also within the medium-sized (Utrecht, Leiden and Dordrecht) urban agglomerations. Red lines, representing *less-than-expected* commuting, are mostly concentrated in zones *directly around* these urban agglomerations. The urban agglomerations are not islands, however; they are interconnected by (stronger than expected) long-distance commuter flows. These larger-than-expected flows are particularly pronounced in the axes Amsterdam–Utrecht and Amsterdam–Leiden–The Hague.

In order to find municipal boundary effects on the empirical origin–destination matrix, we now add in equation (3.2) a variable M for observed municipal boundary crossings of

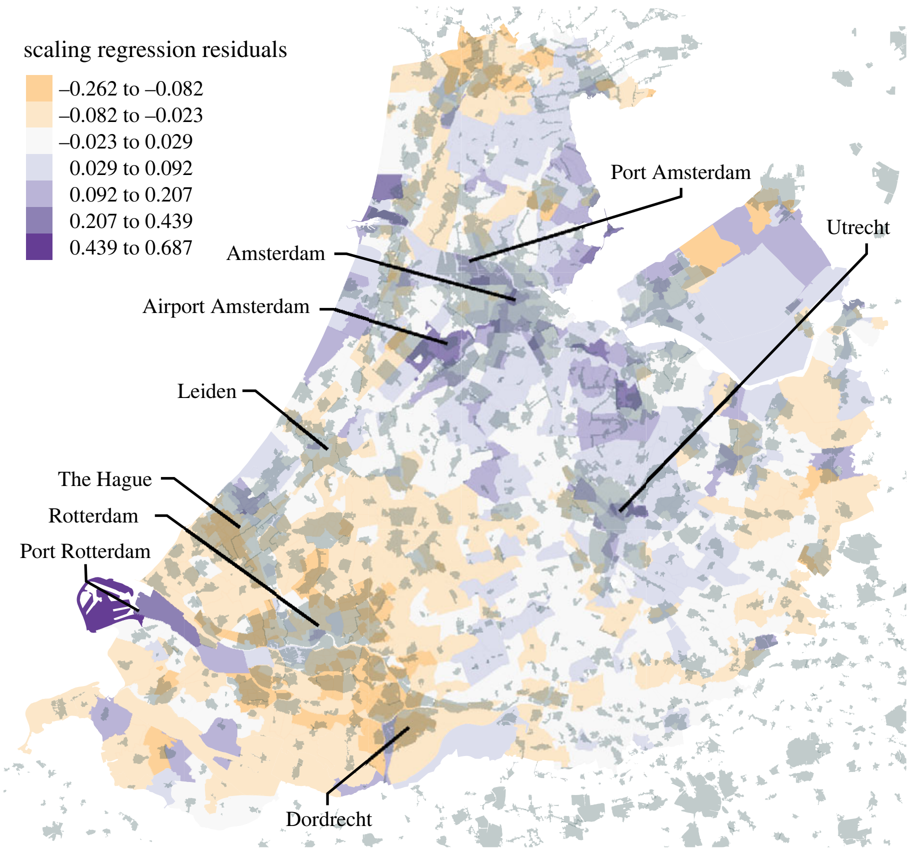

Figure 2. Residual values of micro-scaling of employment in the Randstad region (residual employment per inhabitant).

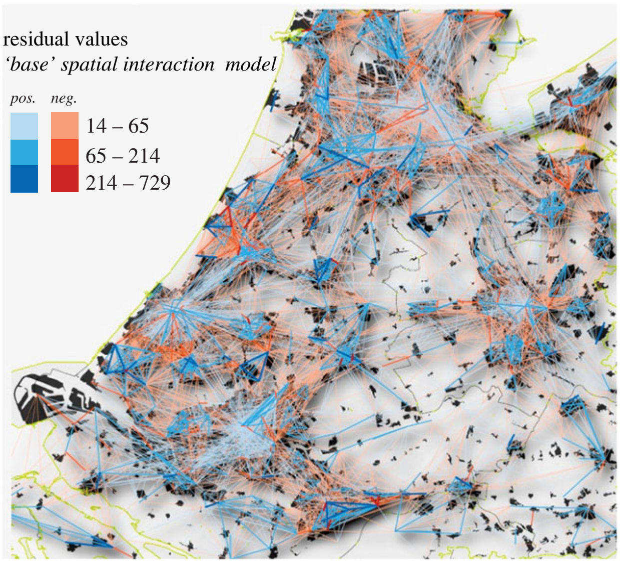

Figure 3. Residual values of commuter flows (T_{ij}) in the Randstad region were calculated with the spatially weighted model. The values are absolute numbers: more (blue lines) or fewer (red lines) observed commutes between postal code areas than expected by the model (note that residual values in figure 2 are deviance residuals).

commutes:

$$T_{ij} = \exp(\kappa + \alpha \log R_i + \gamma \log W_j + \beta \log d_{ij} + \chi M_{ij}). \quad (3.3)$$

The parameter χ describes the observed relationship between municipal boundary crossing M and the size of commuter flows. The municipal boundary variable (M) then simply becomes a dummy variable with value 1 (an individual commuter stays within the boundary of the municipality of residence) or 0 (the boundary is crossed).

The addition of this variable renders clarity to what is actually measured: does the mere fact that a job is located *outside* the municipality of residence affect the propensity of an inhabitant of that municipality to take that job, controlling for the spatial distribution of jobs (W_j^{γ}) and the propensity to travel (d_{ij}^{β})? Theoretically, these boundary effects, if they occur, can be expected to have a disruptive effect on a 'rational' interaction between the population and the economy. For instance: a citizen living near the municipal boundary chooses a specific location for working in his or her own municipality while there is across the municipal border a better job opportunity that would take less travel time and costs. The result is more travel time and less efficient labour markets, which will ultimately come at the expense of overall employment and prosperity.

In order to measure where municipal boundaries influence commuter flows, we apply a *spatially weighted interaction model* (SWIM) on an origin–destination matrix of 1500 postal code areas in the Randstad region. The model is filled with microdata of the residential address (origin) and workplace address (destination) of all employed and tax-paying citizens in the Randstad region. The SWIM is an elaboration of the gravitational spatial interaction model [40–42], whereby parameters of individual locations such as postal codes acquire fitted coefficients on the basis of their weighted position in surrounding areas (or *kernels*) of postal codes, for each of which the interaction model is fitted in a series of model runs.

The resulting origin-focused SWIM takes a multitude of local modelling points u (one for each postal code, extensively discussed in [41]), each with surrounding kernels of 100

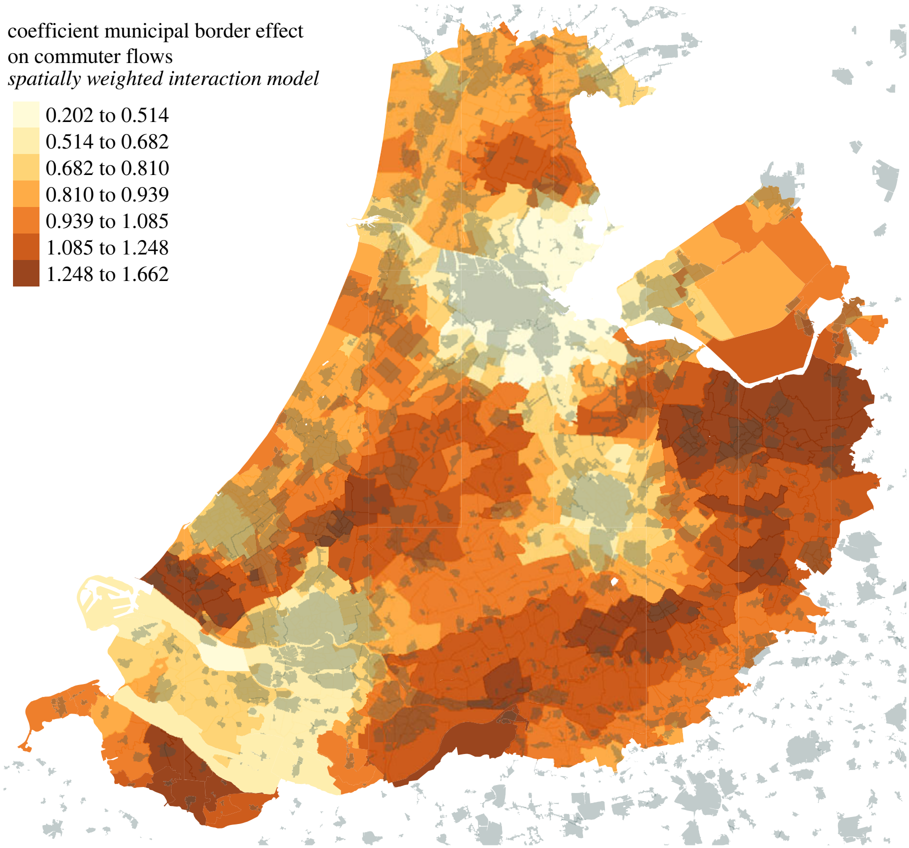

Figure 4. Municipal border effects on commuter flows in the Randstad, measured for postal code areas. Observed local model parameter values of the effect. The higher the local parameter value, the stronger the dampening of inter-municipal commuting by local municipal borders. Source: CBS microdata SSB2017.

postal code areas, for which individual regressions are fitted:

$$T_{ij} = \exp(\kappa\{u,i\} + \alpha\{u,i\}\log R_i + \gamma\{u,i\}\log W_j + \beta\{u,i\}\log d_{ij} + \chi\{u,i\}M_{ij}). \quad (3.4)$$

This spatial weighting procedure allows us to pinpoint specific local municipal boundary effects (M) for each location on the map. The SWIM regression thus takes varying sub-regional circumstances into account, i.e. travel propensities and distance decay exponents that might vary with varying local urban density. Just as the global 'base' model, the SWIM with the municipal boundary variable is estimated through a Poisson regression model (see equation (3.4)).

The fitted M-included model has an adjusted R^2 of 0.82 with p-values for all sub-regional kernels well below $p = 0.01$. Moreover, using the SWIM technique, we can pinpoint the specific effect of individual municipal borders precisely on the map (figure 4). As we can see, the effect of municipal borders (operationalized through the geographically varying χ coefficient) ranges from around 0.5 in mostly central urban areas to more than 1.0 in mostly more rural areas. A local effect of 0.5 means that the propensity of commuting from that location to another location *within* the same municipality will be $\exp(0.5) \approx 1.65$,[6] thus 65% higher than the propensity of commuting to locations *outside* the municipality, holding all other variables including travel times constant. In many areas, this bias to intra-municipal commuting, accounting for competing employment opportunities and travel times to locations in adjacent municipalities, is much more sizeable than that.

The map indicates a highly uneven distribution of municipal boundary barring effects on commuter flows. Comparable with figure 3, there is a strong general pattern. The largest urban agglomerations show relatively little boundary effects within their daily urban systems. The Hague urban agglomeration is an exception to the rule.

At a distance from the large urban agglomerations, particularly in rural areas but also in medium-sized urban agglomerations, municipal boundary effects barring expected commuter flows are much stronger. The exception to the rule is here the rural zone between the Amsterdam and Utrecht urban agglomerations where municipal boundaries do not severely hamper free interaction between these two adjacent areas. This is in sharp contrast with the situation in the south-western part of the Randstad, wherein the Rotterdam and The Hague urban agglomerations, notwithstanding their close vicinity, are divided by an intermediate zone with strong municipal boundary effects barring economic interaction and labour market integration between the two adjacent areas.

This study measures effects of municipal fragmentation, but it does not immediately explain what causes them. The research results prompt some hypotheses about possible causes, however. Theoretically, we could expect strong boundary effects on the dividing lines between large urban agglomerations and adjacent rural areas. A divide of cultural values between typically 'urban' populations and culture and typically 'rural' populations and culture is well documented in the sociological and geographical literature. Rural communities located outside large urban agglomerations might on average be more socially and economically self-contained than urban and suburban communities, and even small villages, that lie within large agglomerations. These social and cultural differences could very well reflect in diverging local municipal institutions and policies, and inward- versus outward-looking attitudes. Because our analysis indicates where effects play geographically, and with the knowledge of local issues and characteristics in mind, hypotheses about actual causes for the barring of inter-municipal commuting and labour market fragmentation can be drawn up for testing in further research.

3.2. Second analytical step: relating boundary effects to employment-scaling residuals

In the previous section, we *localized* the municipal boundary effects on spatial interaction (commuter flows). As a next and second step, we measure to what degree these local effects are *related to economic performance* in terms of employment. On the theoretical assumption that spatial economic interactions—among which commutes—drive urban scaling, we would expect that local municipal boundary effects on interaction are negatively related to local employment. Controlling for local population size and thus for urban scaling, boundary effects could explain the negative employment-scaling residuals that we showed in figure 2. However, there is an important caveat to this assumption. The assumption is basically about the efficient functioning of markets, labour markets in our case. Free movement of a large number of participants is prerequisite for efficiency in market theory. In social theory, however, a closed 'club' or 'clan' of actors can also generate positive economic outcomes, under specific circumstances even better than markets can do [45]. For example, small and relatively isolated towns or regions can specialize in trades by making use of strong social and family ties. Such economically vibrant local communities abound in the rural areas within the Randstad region. Thus, observed municipal boundary effects in rural areas outside urban agglomerations could very well be unrelated or even positively related with local economic performance, depending on the social embeddedness of the local economy [46].

In this final step, we evaluate how the localized municipal boundary effects (i.e. the model coefficients for each postcode from the previous SWIM) relate to the residuals of the urban scaling model in §2.3. We do this by estimating a linear regression model in which the residuals from the scaling model are regressed on the localized boundary effects:

$$e = c + b\chi, \tag{3.5}$$

where e represents the residuals from the urban scaling model, χ is the localized municipal boundary effect, and c is a constant. The estimated coefficient b then gives us an indication about the direction and size of the relation between the localized municipal boundary effect and the residuals from the scaling model. This relationship depends indeed on the local, urban or rural context. A global and spatially *un*weighted regression of municipal boundary effects and employment-scaling residuals for the whole Randstad does for that reason not render a model with a high explanatory power. However, things change when we apply a geographically weighted regression (similar to the SWIM interaction model in the previous section) and take thus local and subregional particularities into account. In many areas, there is no significant relation between boundary effects and employment residuals, but in specific areas, this relation is certainly present and in most cases negative (figure 5).

Figure 5 shows that the municipal boundary barriers to commuting in many more rural areas outside the main urban agglomerations do not, in the majority of cases, affect local employment performance. This result could be expected from social theory [45]. Negative boundary effects on employment do exist, however, within or at the fringe of large urban agglomerations, as expected by economic market theory [46]. Negative performance effects are particularly present in areas dominated by 'blue collar' employment: the large logistical and industrial complexes west of Rotterdam, Amsterdam and Utrecht, and in the vicinity of the Amsterdam International Airport Schiphol. The detrimental economic effect of municipal barriers to commuting could in the case of these complexes very well be explained by their off-centred geographical position within the urban agglomerations, due to their extensive land use. Off-centred positions within large urban agglomerations make for long commuting times for the workforce within an agglomeration. Commuting times from adjacent more rural areas can be much shorter, but here the barring effects of municipal borders come into play. A closer look at commuting patterns of workers in the Rotterdam port area substantiates this explanation (figure 2). Notwithstanding long commuting times to the port, the vast majority of port workers live in or close to the city of Rotterdam. The role of rural communities adjacent to port areas is much more limited in this respect. We see a comparable phenomenon around Schiphol Airport, where many workers are drawn from the relatively distant city of Almere, lying east of Amsterdam and making an integral part of the Amsterdam agglomeration. Commuting from more adjacent communities south of the airport is less than expected.

In the case of the Rotterdam agglomeration, detrimental economic effects of municipal fragmentation extend even to large parts of the central city. The absolute volume of the negative employment effect is therefore quite sizeable in this case, taking into consideration that Rotterdam is the second largest city and employment centre in The Netherlands. A main explanation for this effect on the Rotterdam economy could be found in the relatively dense concentrations of commuting-barring municipal borders in the immediate vicinity of the city, among which is the barring zone between the Rotterdam and The Hague agglomerations (figure 4). The fragmented structure of municipalities, and urban and rural areas in the highly urbanized southern part of the Randstad could explain at least partially not only the substandard employment performance of Rotterdam (benchmarked against the urban employment-scaling line for the entire Randstad), but as well the substandard performance of the southern part as a whole.

The urban core of The Hague represents in this respect an exception to the rule. This core seems to benefit in terms of employment from barring municipal boundary effects. A possible explanation for this counterintuitive result might lie in the particular nature of the local employment complex, being the seat of national government and many international institutions. The specialist nature of work in this complex results in a geographically highly extended labour market, encompassing the entire Randstad and beyond (figure 3). Average commuting times are long. The dense commuting-barring zone directly around the city (figure 4) is for this complex thus less relevant and surpassed. For the mid- and low-level workers in the complex, municipal boundary effects could even work as a protective shield.

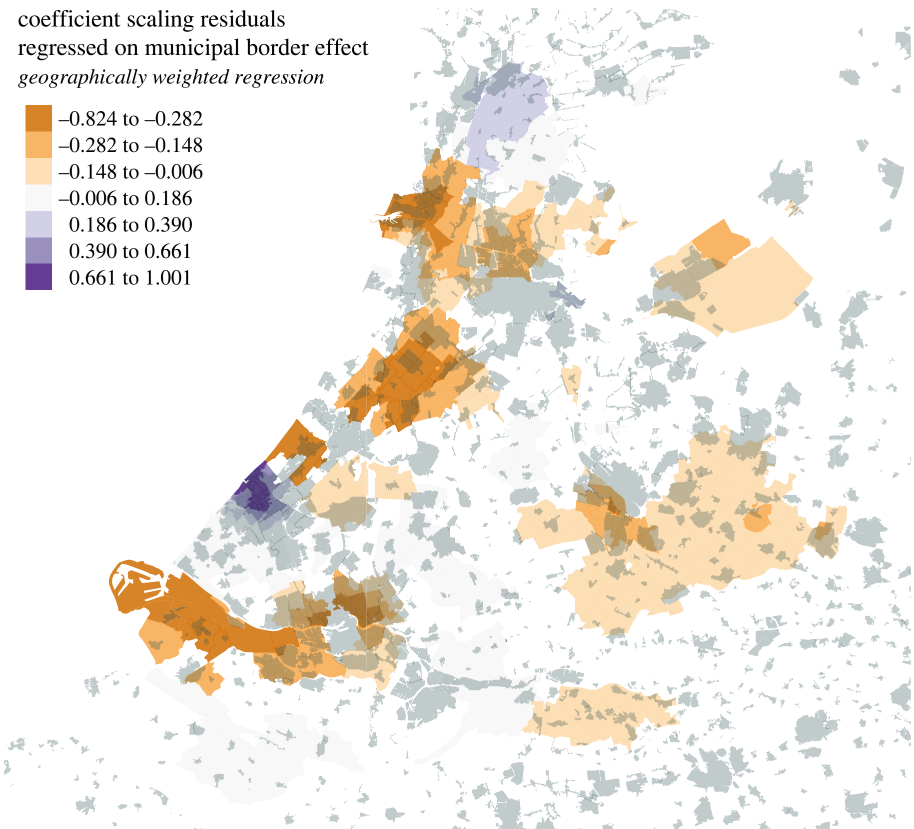

Figure 5. Local employment-scaling residuals explained by local municipal boundary effects on commuter flows (spatially weighted regression of boundary parameter values): specific coefficients of the local relation. Orange areas: border effects act as barriers and push local employment downwards. Purple areas: border effects act as protection and push local employment upwards.

4. Discussion and conclusion

Urban population scaling of economic performance, including employment, is caused by human interaction. In advanced and urbanized economies, activities spring from and settle in nodes of interaction networks. The wider the 'feeding' area for these nodes, the more they can thrive in a market economy. Barriers for interaction are detrimental to this mechanism, but more isolated areas could draw on tight local bonds to bypass the market. In this study, we investigated the impact of municipal boundaries on interaction networks (commuting) and, via this, local economic performance (employment), controlled for general population scaling. To find boundary effects, we descended to the local micro-level and applied a spatial gravity model that proved to render reliable results.

There is little research on the influence of governance structure in urban agglomerations on socio-economic development [1,2]. Municipalities are entities with a very high degree of autonomy explicitly laid down in the constitutional law of the countries involved. A municipality implies a local government formed by the municipal council elected in nationally organized elections and headed by a mayor appointed by the head of state. Formally, one could see municipalities as an 'administrative subdivision' of urban agglomerations. But the term 'administrative subdivision' sounds like a bureaucratic subdivision of, for instance, cities into neighbourhoods or so. It is not an appropriate terminology for an entity that has a crucial position in constitutional law. Using terminology that can be felt, and possibly works, as a derogatory qualification of municipalities is probably related to the, in our opinion, gross underestimation in urban science research of the role of municipalities, in particular underestimation of the effects of municipal boundaries.

In the case of the densely populated Randstad region in The Netherlands, we found that municipal boundaries do indeed in many cases bar inter-municipal interaction in terms of labour commuting. Barring boundaries are rather ubiquitous in rural areas, but less so within urban agglomerations. However, the economy of urban agglomerations can significantly suffer from municipal barring effects, particularly at extensive industrial and logistical complexes at the urban fringe. In the case of the Rotterdam agglomeration, detrimental employment effects of barring municipal boundaries—that almost encircle the city—extend even to the urban core. Thus, particularly at intersections of urban and more rural areas, municipal boundaries act as a brake on labour mobility and the matching of supply and demand of talent and skills. Potential economies of scale and synergy are thus not converted into prosperity. As a result, the population in large agglomerations and central cities does not benefit optimally from activity growth in nearby smaller centres, and smaller centres do not benefit optimally from central urban functions.

These institutional boundary effects do not explain all employment deviations; other factors are at play as well. For instance, we did not investigate reasons behind border effects. But we can surmise that social, economic and cultural divides between the often closely knit communities predominant in rural areas, and the more individualistic, liberal and market-oriented population in large urban agglomerations, play a role. Such divides could of course also cut *through* municipalities, causing local employment deviations that relate less with municipal boundaries. With the technique of spatially weighted regression fitting microdata, it is possible to test this hypothesis in further research.

This study, part of a research programme on the relation between governance structure and regional economic development in the province of South-Holland [47,48], indicates that potential economic agglomeration benefits are not being sufficiently exploited, while they could be an important source of further prosperity. Our observation that governance boundaries influence employment negatively in significant employment complexes, particularly large parts of the Rotterdam agglomeration, is in this respect a relevant research outcome for the practical organization of local and regional governance, with the aim of economic prosperity and competitiveness.

The global transition of the economy—characterized by, particularly, knowledge intensification, ICT and big data, digitization and robotization—does not automatically lead to an economy in which physical interaction, accessibility and proximity are irrelevant. On the contrary, agglomeration, regional and spatial interaction, cohesion and synergy in the urban context are important for economic competitiveness and prosperity. Understanding the foundations for this spatial cohesion, and the stimulating or hindering role of governance boundaries, is crucial for policymaking. Is policy for spatial economic facilities and conditions such as business parks, science parks, accessibility networks and efficient labour markets picked up at an optimal spatial scale? Is optimal use made of potential agglomeration benefits and do governance structures still match with the contemporary dynamics of the spatial economy? The conclusion from an in-depth analysis of the province of South-Holland is: no [47,48]. It is logical and inevitable that economic development, interactions and synergy extend beyond municipal boundaries. The Netherlands Environmental Assessment Agency points out in a recent report that the economy functions on a larger scale than the governance boundaries of urban areas [49]. Consistency and synergy of governance in an expanding urban agglomeration context are becoming crucially important.

Data accessibility. The data analysed in this paper are derived from register data that are made available for research purposes by Statistics Netherlands (Central Bureau of Statistics). Researchers can find more information and apply for access through https://www.cbs.nl/en-gb/our-services/customised-services-microdata/microdata-conducting-your-own-research. The aggregated data used for the models and figures in this paper are available from the authors upon request. The bibliometric data are available from the Open Science Framework: https://osf.io/4ru96.

Electronic supplementary material is available online [50].

Authors' contributions. P.P.T.: conceptualization, data curation, formal analysis, investigation, methodology, software, supervision, validation, visualization, writing—original draft and writing—review and editing; A.F.J.v.R.: conceptualization, data curation, formal analysis, investigation, methodology, software, supervision, validation, visualization, writing—original draft and writing—review and editing; A.P.: data curation, formal analysis, investigation, methodology, software, validation, visualization and writing—review and editing.

All authors gave final approval for publication and agreed to be held accountable for the work performed therein.

Conflict of interest declaration. We declare we have no competing interests.

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Endnotes

[1]Throughout the text of this paper, we use the abbreviation GUP for the gross urban product. In the case of equation (2.1), we use the shorter symbol G.

[2]In The Netherlands, a complete postal code is six digits, namely four numbers and two letters (e.g. 2311 AC; these six-digit postal codes concern areas with about 100 inhabitants); in this study, we go one aggregation level higher, i.e. the four digits (e.g. 2311; these four-digit postal codes concern areas with about 4000 inhabitants).

[3]The data are from LISA, the database of business locations in The Netherlands: https://www.lisa.nl/home. The LISA data are based on location level which means one specific address of a company or institution. The number of employed persons is registered annually at that location, broken down by gender, full-time/part-time (hour limit 12 h per week). Thus, all data are collected and registered per location, and not at a higher aggregation level, as is customary at the Central Bureau of Statistics. The LISA database consists of 1 630 070 locations (2018). All higher level data such as at the municipal level are aggregations of these location level data.

[4]Data source: Central Bureau of Statistics Netherlands (CBS): microdata SSB (Social Statistical Databases) and ABR (General Business Register) 2016. See https://www.cbs.nl/en-gb/our-services/customised-services-microdata/microdata-conducting-your-own-research/microdatabestanden/abr-general-business-register.

[5]Microdata about these commuter interactions are from the CBS, in particular data concerning living and working addresses of employed persons (CBS-SBB 2017).

[6]The coefficient is exponentiated here due to the log-linear model specification.

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