How do neighbouring populations affect local population change over time?

Författare 1: Mengjie Han
Författare 2: Johan Håkansson
Författare 3: Lars Rönnegård

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Mengjie Han, Johan Håkansson, Lars Rönnegård

Dalarna University

Borlänge, Sweden

Abstract: This study covers a period when society changed from a pre-industrial agricultural society to a post-industrial service-producing society. Parallel with this social transformation, major population changes took place. In this study, we analyse how local population changes are affected by neighbouring populations. To do so we use the last 200 years of local population change that redistributed population in Sweden. We use literature to identify several different processes and spatial dependencies in the redistribution between a parish and its surrounding parishes. The analysis is based on a unique unchanged historical parish division, and we use an index of local spatial correlation to describe different kinds of spatial dependencies that have influenced the redistribution of the population. To control inherent time dependencies, we introduce a non-separable spatial temporal correlation model into the analysis of population redistribution. Hereby, several different spatial dependencies can be observed simultaneously over time. The main conclusions are that while local population changes have been highly dependent on the neighbouring populations in the 19th century, this spatial dependence have become insignificant already when two parishes is separated by 5 kilometres in the late 20th century. Another conclusion is that the time dependency in the population change is higher when the population redistribution is weak, as it currently is and as it was during the 19th century until the start of industrial revolution.

Keywords: population redistribution, spatial dependency, Moran’s I, non-separable time space correlation model, Sweden
INTRODUCTION

This study extends over a period when society changed from a pre-industrial agricultural society to an industrial society with mechanisation and wage labour and, from an industrial to a post-industrial service-producing society during the latter part of the period. Parallel with this social transformation, major population changes took place. Consequently, the geographical distribution and redistribution of the population has been a constantly recurring research theme in geography and in other disciplines.

Over past decades substantial research focused on urbanization. However, the research touched upon concentration and dispersion, and the population redistribution phenomena was structured at different geographical levels internationally (e.g. Champion and Hugo 2004, Geyer and Kontuly 1996, Pounds 1990, Van der Woude, De Vries and Hayami 1990) and in Sweden (Eneqvist 1960, Norborg 1968, Andersson 1987, Håkansson 2000a, Nilsson 1989, Norborg 1999).

One problem with geographical population studies over long time periods is accessing data that has unchanged spatial divisions (e.g. Gregory and Ell 2005). This problem has forced much of the research to be either case studies often with relatively detailed information except for a limited geographical area, or studies with larger study areas, such as countries or even larger areas, spanning over long time periods with often relative low spatial resolutions.

The long term redistribution in Sweden was studied with a high spatial resolution by Håkansson (2000a). It was shown that the distribution of a population on a regional level at 75% was the same in 1990 as it was in 1810. It was also shown that on a local level the distribution at 50% was the same in 1990 compared to 1810. Hence, it was concluded that the redistribution of a population has mainly been a local redistribution. The reasons for this are that most migration covered a short distance and that migration was a selective process. The implication is that there should be a measurable statistical dependency between population changes in neighbouring areas. The nature of this relationship depends on what redistribution process is at work at the time. Therefore, our aim is to analyse how and to what extent neighbouring populations affect local population change.
We uses the whole of Sweden between 1810 and 2000 for our study. To do so, we use a unique data set with population figures in parishes for every 10\textsuperscript{th} year. The parish division change over time. However, an unchanged geographical division over time has been constructed. The unchanged parish division consists of 1840 parishes. To our knowledge this spatial division is the lowest possible geographical level that is feasible to use for population studies of this kind and with this time perspective in Sweden. Even in an international perspective we are not aware of studies with this fine spatial division covering such a long time period and large geographical area. We are just interested in population changes that are part of the redistribution of the population. Therefore, based on the population figure, each parish’s population share of the total population in Sweden and its change is calculated. To conduct the spatial statistical analysis, we first use an index of spatial autocorrelation, local Moran’s I (Anselin 1995). Furthermore to control for temporal correlation, we fit a non-separable statistical spatial-temporal correlation model to analyse how the population changes over time and space (see Cressie and Wikle 2011, Gneiting 2002). To our knowledge it is the first time such a model is used to analyse population redistribution over long time periods.

This paper is organized as follows: section two presents a short literature review over the main processes that have redistributed the population in Sweden since the beginning of the 19\textsuperscript{th} century. In section three, the data and the empirical setting are presented and discussed. Section four presents the methods used in the spatial analysis. Section five gives the results. Section six concludes the paper.

LITERATURE REVIEW

Several processes that have redistributed the population in Sweden have been described in the literature. Many of them, especially those dealing with the redistribution during the 19\textsuperscript{th} and early 20\textsuperscript{th} century, are conducted as case studies with a relatively limited geographical area as the study area.

Combining them together gives a picture of the redistribution in Sweden and that several different processes can be at work at the same time. For instance, it is obvious that the
colonization of the interior parts of northern Sweden occurred at the same time as the emigration to the US.

In this section we shortly review the major processes that redistribute the population described in the literature, and we discuss how they affect the local population change between neighbouring parishes.

(1) Colonisation: several studies show how the frontier of colonisation has been moved inland in Sweden’s northern regions (Norrland) throughout the 19th century (e.g. Enequist 1937, Hoppe 1945, Bylund 1956 & 1968, Rudberg 1957, Egerbladh 1987). It appears that a large part of this colonisation took place through the population already living in northern Sweden starting new settlements constantly further inland from the coast. High fertility levels are an important explanation as to why a pool of colonizers evolved. However, migration from southern Sweden also took place. Colonisation in Norrland continued for a couple of decades into the 20th century. Since colonisation is a means in which new settlements evolve close to each other we expect a spatial dependency in which a parish with a population increase is surrounded by other parishes also expiring population increase.

A number of settlement history studies also show a course of colonisation at the micro level in southern and central Sweden during the early and mid-part of the 19th century due to population pressure and to enclosure revision (e.g. Dahl 1941, Arpi 1951, Eriksson 1955, Hoppe and Langton 1994). These reveal that the division of villages led to a colonisation of the thinly populated outlying lands. We expect this process to find a spatial dependency in which a parish with population decrease is surrounded by other parishes, population increase due to colonisation.

(2) Emigration: There was a great drain of population to North America (e.g. Sundbärg 1910, Atlas över Sverige 1960, Tedebrand 1972, Norman 1974, De Geer 1977, Norman & Rundblom 1980). From emigration studies it is clear that the emigration during the latter part of the 19th and early part of the 20th centuries was relatively greater from urban areas than from rural areas (Norman 1974, De Geer 1977, Norman & Rundblom 1980). However at first, emigration was mainly from southern Sweden. Later when emigration from Norrland occurred, fewer
people were involved. The loss of around million individuals undeniably had spatial consequences, as did the later addition of return migrants from North America (Tedebrand 1972, Lindblad 1995). We expect emigration to be a process in which a parish with a population decline is surrounded by other parishes undergoing the same development.

(3) Depopulation of rural areas – Countryside urbanisation: at the micro level the depopulation process began relatively early in southern Sweden (e.g. Nordström 1952, Edestam 1955, Eriksson 1974). When urbanisation started, it first took place in the countryside where relatively many smaller towns developed. Several economic historical studies about sawmill and industrial communities show how the population moved in from the immediate surroundings (e.g. Godlund 1954, Hjulström & Arpi & Lövgren 1955). Others also demonstrated the connection between the building of railways and the growth of new towns along their routes (e.g. Heckscher 1907, Elander, and Jonasson 1949).

Urbanisation: A larger number of studies show that the process of urbanisation changed after the end of the Second World War. People did not move merely from the countryside to towns. Instead, major towns experienced a powerful growth in population, while migration to southern Sweden increased, above all from Norrland (e.g. Bylund & Norling 1966). A number of studies focused on explaining the migration patterns in this stage of the urbanisation process (e.g. Godlund 1964, Wärneryd 1968, Jakobsson 1969, SOU 1970, Falk 1976). Selective migration during urbanization changed the age structure so much that the regional differences in mortality and fertility patterns have changed to such an extent that the natural population changes currently concentrate the population (Håkansson 2000b). Due to urbanisation we expect to find parishes with population increase surrounded by other parishes with population decrease.

(4) Immigration: In the 1930s Sweden became a net-immigration country. It is clear from the literature that immigration is one of the major contributions to population distribution during the post-war period. During the 1960s there was a boom of labour immigration. This went mainly to the major metropolitan areas and to industrial towns in southern Sweden (Hammar 1975, Andersson 1993, Borgegård & Håkansson 1997). In the 1970s and 1980s reasons for
immigration changed. Immigration due to war and persecution became the most common reason. To an extent larger than before new immigrant groups settled in the three metropolitan regions in Sweden, Stockholm, Gothenburg and Malmö, even though there was a policy at work during the 1980s that first dispersed the immigrants. Immigration can be assumed to concentrate the population towards the largest urban areas. Since the immigration population is growing in the larger cities, we expect they are going to live in more and more parishes. Therefore, we expect a similar spatial dependency as for colonisation on local level implying that a parish with population increase is surrounded by others with population increase.

(5) Suburbanisation: During the 1960s and 1970s a growing number of dwellings began to be constructed in the fringe areas of towns. At the same time, suburban areas were built up outside the towns (e.g. Lewan 1967, Bodström, Lindström & Lundén 1979, Nyström 1990). Many smaller settlements on the fringes of towns, were also incorporated within the expanding towns (Johansson 1974). Explanations for this spread of built-up residential areas within the urban landscapes have been analysed in a number of studies (e.g. Lewan 1967, Holmgren, Listérus, Köstner & Nordström 1979, Lövgren 1986). The fringe areas and suburbs became places of residence for an increasing part of the population. We therefore expect to see a spatial dependency pattern in which a parish with population decline is surrounded by other parishes with population increase.

(6) Counterurbanisation: During the 1970s the patterns of migration were changed as the larger towns experienced outmigration while the smaller towns and the countryside experienced immigration (Ahnström 1980, Forsström & Olsson 1982, Nyström 1990, Forsberg 1994, Borgegård, Håkansson & Malmberg 1995, Amcoff 2001). A few studies have pointed out the reasons for the stagnation in the big cities (e.g. Ahnström 1980, 1986). Several studies deal with the expansion and condition of middle-sized towns (e.g. Andersson & Strömgren 1988, Eriksson 1989, Kåpe 1999). Some studies demonstrate the importance of the demographic components for population development in a number of different types of municipality (Borgegård & Håkansson 1997, Håkansson 2000b). Other studies also point to the continued expansion of the major cities’ commuter districts and to the continued spread of settlements that are not tied to
the suburban areas (Forsström & Olsson 1982, Nyström 1990, Forsberg & Carlbrand 1994, Amcoff 2001, 2006, Lindgren 2003). Based on the literature, we expect to see the same spatial dependency pattern as for suburbanization.

Table 1. Concentration and Dispersion of the population in Sweden at local and regional level.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Local</td>
<td>dispersion</td>
<td>concentration</td>
<td>concentration</td>
<td>dispersion</td>
</tr>
<tr>
<td>Regional</td>
<td>dispersion</td>
<td>dispersion</td>
<td>concentration</td>
<td>concentration</td>
</tr>
</tbody>
</table>

Most of the work about the redistribution of population referred to above is highly limited time-wise. However in some studies, population redistribution is dealt with over long periods and therefore partially bridges the temporal limitations (e.g. Eneqvist 1960, Lewan 1967, Norborg 1968 and 1974, Hofsten & Lundström 1976, Guteland, Holmberg, Hägerstrand, Karlqvist & Rundblad 1975, Andersson 1987, Söderberg & Lundgren 1982, Hägerstrand 1988, Nilsson 1989, Borgegård, Håkansson & Malmberg 1995, Norborg 1999, Bäcklund 1999, Håkansson 2000a). From these studies and the ones reviewed above, it is relevant to divide the redistribution during the last 200 years into different time periods. The time periods and the dominating direction in the population redistribution are shown in Table 1. In Figure 1 the distribution of the populations in 1810 and 1990 are given. It illustrates that the effects of 200 years of population redistribution have led to a distribution where there are large differences in population densities between nearby located parishes. This is a pattern of a highly urbanised population. Beside that, the similarity in how the populations’ are distributed in 1810 and 2000 is striking. From the figure it is also obvious that the large numbers of parishes that have undergone a population decline are located in the southern part of Sweden. Their distribution across southern Sweden is intermingled with the parishes with population increase. This together lends support to the idea that the redistribution in Sweden has mainly been a process in which nearby parishes are dependent on each other.
Figure 1. Population density in Swedish parishes in 1810 (a) and 1990 (b) as well as the annual population change between 1810 and 2000 (c).

Based on this literature review, we can identify four different expected local spatial dependencies that work under different population redistribution processes (Table 2). As the population has grown significantly in Sweden since the beginning of the 19th century, we look at these spatial dependencies as changes in the share of the total population. All of these four different forms of spatial dependencies can be measured. However a fifth form, the non-spatial dependency, could exist. The possible existence of a non-spatial dependency can have different meanings depending on how and when it occurs. One obvious reason as to why a non-spatial dependency does not occur is that the spatial dependencies defined here are wrong. Another reason could be that the spatial structure used in this study is too crude and does not capture the spatial dimension in which the processes take place. Another explanation is that the processes that are evaluated here are too weak as population redistribution processes, and
they just have minor impact on the distribution of the population. These could be described as social processes with a spatial dimension.

Table 2. Expected local spatial dependencies between a parish’s population change and the population change in its surrounding parishes.

<table>
<thead>
<tr>
<th>Population change in a parish’s surrounding</th>
<th>A parish’s population change Increase (H)</th>
<th>Decrease (L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase (H)</td>
<td>- Colonisation in Northern Sweden</td>
<td>- Colonisation on southern Sweden</td>
</tr>
<tr>
<td></td>
<td>- Immigration</td>
<td>- Suburbanisation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Counter urbanisation</td>
</tr>
<tr>
<td>Decrease (L)</td>
<td>- Urbanisation</td>
<td>- Emigration</td>
</tr>
</tbody>
</table>

DATA AND METHODS

Data

This study is based on a material based on population numbers for administrative parish units and certain parish registrations from the Swedish agencies Tabellverket and Statistics Sweden (www.scb.se). The population returns are for every tenth year between 1810 and 2000. Altogether the material contains 2,615 geographical units.

The parish division changes over time. Different methods on how to create a consistent spatial division over time is discussed by Gregory and Ell (2005). Their aim is to find automatic methods for estimating the population size in regions having borders changing over time. However, our approach is to sacrifice some spatial details for parishes defined by clear and unchanged borders over time, so that the spatial correlations can be modelled in detail. To create a spatial division over time, we started with assigning the population in each parish to a church co-ordinate from 1972 (SCB 1972). The church coordinate is chosen because the church in most parishes is located with relatively high centrality in relation to the parish inhabitants. Information about boundary changes merges and divisions that involve transfers of people (see Sveriges församlingar genom tiderna 1989) have been used to organize a spatial parish division over time. This was achieved by merging parishes whenever a parish changed through: merging, division or boundary changes. In a last step, these churches are given the parish boundaries that existed in 1990. Every parish without a church coordinate is identified and merged to a parish that it had been merged to or divided from. The spatial division is then further adjusted
to the 2000 spatial parish division. After merging, the unchanged spatial division consists of 1840 historical parishes (see Figure 2a).

Figure 2. A historical unchanged parish division (a) and present time parish areas which have been merged with other parishes due to changes in the parish division 1810-2000 (b) in Sweden.

The reduction of parishes in this process varies regionally (Figure 2b). The losses are largest in the sparsely populated areas in the interior parts of the northern Sweden and in the cities. Further, the regional differences in the number of analysed units influence the spatial detail for
the analysis of population redistribution. A more exhaustive description of the data and the work to create unchanged parish division is given in Håkansson (2000a).

**Local Moran’s I**

As shown by the literature review; we can expect that several different processes that redistribute the population are at work simultaneously, and that they result in different spatial dependencies. To obtain an understanding of how neighbouring populations affect the local population change in a parish, we first analysed the spatial autocorrelation in the population redistribution from each parish separately. We therefore implemented Anselin’s Local Moran’s I in a GIS (Anselin 1993, 1995). The index \( I(l) \) here is given from the parishes weighted by their population change rate. The method then identifies parishes whose percentage populations change rates correlates. Let \( p_{x,t} \) be the proportion of the entire population at time \( t \) living in parish \( i \), and let the observed change \( x_i \) in a given year \( t \) be defined as \( x_i = p_{x,t} - p_{x,t-1} \). We calculated Local Moran's I index \( (I_l) \):

\[
I_l = \frac{x_i - \bar{X}}{S_i^2} \sum_{j=1, j \neq i}^{n} \omega_{i,j}(x_i - \bar{X})
\]

where

\[
S_i^2 = \frac{\sum_{j=1, j \neq i}^{n} \omega_{i,j}}{n-1} - \bar{X}^2
\]

\( \bar{X} \) is the mean of all \( x_j \) and \( \omega_{i,j} \) is the spatial weight between location \( i \) and \( j \). The expectation of \( I_l \) is \( EI_l = -\sum_{j=1, j \neq i}^{n} /n - 1 \) and the variance of \( I_l \) is \( DI_l = EI_l^2 - (EI_l)^2 \). A z score,

\[
z_{I_l} = \frac{I_l - EI_l}{\sqrt{DI_l}}
\]

was calculated as the normalized value of \( I_l \), which indicates if \( I_l \) is significant or not. The non-significance is identified when the z-score falls between the 0.05 level critical values \( \pm 1.96 \) of empirical normal distribution. A positive value for \( I_l \) indicates that a parish is surrounded by other parishes with similar percentage populations change rates. Such a
correlations is part of two types of spatial clusters (HH and LL in Table 3) if they are statistical significant at a (0.05 level). A negative value for $I$ indicates that a parish with a certain percentage population change rate is surrounded by other parishes with different percentage population change rates. Such a parish is considered as an outlier in a cluster if the correlation is statistically significant (0.05 level) and this gives two other types of spatial clusters (HL and LH in Table 3). The different types considered in this study are summarized in Table 3. In the table, a fifth category of a non-statistical significant relationship between parishes’ percentage population change rates is added. These defined spatial dependencies correspond with those expected as identified in the literature review (see Table 2).

Table 3. Spatial correlations in the population redistribution measured with Local Moran’s I.

<table>
<thead>
<tr>
<th>Spatial correlations</th>
<th>The spatial relationship between parishes in the population redistribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>HighHighValues (HH)</td>
<td>Parishes with relative high population increase surrounded by other parishes with high relative population increase</td>
</tr>
<tr>
<td>HighLowValues (HL)</td>
<td>Parishes with relative high population increase surrounded by other parishes with fast relative population decrease.</td>
</tr>
<tr>
<td>LowHighValues (LH)</td>
<td>Parishes with fast relative population decrease, surrounded by other parishes with high relative population increase</td>
</tr>
<tr>
<td>LowLowValues (LL)</td>
<td>Parishes with fast relative population decrease, with similar developments in surrounding parishes</td>
</tr>
<tr>
<td>No significant relationship</td>
<td>Parishes relative population change is taken place randomly in space</td>
</tr>
<tr>
<td>at 0.05 level</td>
<td></td>
</tr>
</tbody>
</table>

In the analysis, the parishes influence on a spatial cluster is weighted depending on their distance to the evaluated parish. We used an inverse distance decay function to weight the surrounding parishes. Further, we chose to limit the area taken into account in the Local Moran’s I analysis around the parishes to 86 km. The distance limit is chosen so that every parish that is evaluated has a least one other parish to be evaluated against. However, we tested to set the outer limit for the area of interest to 20, 50, 60 and 70 km. The results of the analysis remain more or less the same.
The spatial-temporal correlation model

With the above described index, we only consider observations between parishes located in spatial proximity to each other. However, it is important to include a temporal dimension because observations of population change are time dependent and there are tendencies for each spatial unit to inherit features from the previous time period. To study correlation both in space and time, we now consider a spatial-temporal correlation model.

To do so we first need to define the spatial temporal process. Recall that $p_{t,x}$ was defined as the proportion of the entire population at time $t$ living in parish $x$. Let the observed change at an arbitrary time $t$ be defined as $z_{t,x} = p_{t,x} - p_{t,x-1}$. For these observations we have a spatial-temporal Gaussian process for $Z(s; t)$ where $Z(s; t)$ is a random variable of the population change in space $s$ and time $t$. In the spatial-temporal analysis, the covariance $C$ describes the relationship between nearby observation in time and space $\text{cov}(Z(s; t), Z(s + h; t + u)) = C(h; u)$. Here $s + h$ is the increase in spatial distance and $t + u$ is the increase in time, and all elements in $C$ are assumed to be non-negative.

For a covariance model assumed to be separable (as it often is), $C(h; u)$ can be written as $C(h) \cdot C(u)$. However, these kinds of separable covariance models often produce erroneous results when applied to real world data (e.g. Cressie 2011). Due to this, we turn to a non-separable covariance model which not only considers a product of spatial and temporal covariances, but also the interaction between them (e.g. Cressie and Huang 1999, Gneiting 2002, Stein 2005). We use a non-separable covariance model suggested by Gneiting (2002):

$$C(h; u) = \frac{\sigma^2}{\|u\|^{2\alpha + 1}} \exp \left( \frac{-c \|h\|^{2\omega}}{\|u\|^{2\alpha + 1}} \right)$$

(1)

and the parameters to be estimated are $\sigma^2, \alpha, \beta, \omega$ and $c$. The parameter $\beta$ describes the interactions between space and time and can take values from 0 to 1. For $\beta = 0$, the covariance function is separable, and for large $\beta$ there is a strong dependency. The parameters were estimated by minimizing the difference between observed and fitted variograms (see Appendix).
RESULTS

Spatial dependencies between local population change and neighbouring populations

To analyse the question of how local population change is affected by neighbouring populations, we first turn to the question regarding the extent of which different local spatial dependencies existed in the population redistribution. To answering this question, we used Moran’s I to search for clusters of different spatial dependencies defined in Table 3. Figure 3 shows that different clusters of spatial dependencies affecting the population redistribution co-exist at the same time and that the spatial dependencies change over time. In addition, note that all of the four different spatial clusters identified and defined in this study (HH, HL, LH and LL see Table 2 and 3) have existed in the redistribution of the Swedish population.

Figure 3. Spatial correlations between proximity located parishes in the population redistribution in Sweden 1810 to 2000 during different sub periods.
The most wide spread and long lived form of cluster of spatial dependency in Swedish population redistribution is the one with a parish that has a fast population increase and which is surrounded by neighbouring parishes experiencing fast population increase (HH-clusters). This type of spatial autocorrelation is at work early in the study period and is common in the northern parts of Sweden as well as in and around the three metropolitan areas. Expected spatial dependencies of colonisation in northern Sweden and from immigration could therefore be observed.

There are also clusters resulting from urbanisation the expected spatial dependency, with a single growing parish surrounded by parishes with population decrease (HL-clusters, Figure 3). However, HL-clusters in the population redistribution are mainly at work in the southern part of Sweden. Even though HL-clusters can be noted in the early 19th century, it is most common during the 20th century. Within the southern part of Sweden it is also notable that the frequency by which HL-clusters can be observed alternate over time between the different parts.

Clusters with parishes with a population decrease and surrounded by other parishes with a similar population change (LL-clusters), is, for a long time, co-existing in the southern part of Sweden with mainly HL-clusters. At the beginning of the study period, the LL-clusters are at work first in almost every parish in areas around the capital city of Stockholm stretching to the west and north-west throughout the district of Bergslagen. Later, the centre of gravitation for this type of cluster moved further south to some of the agricultural heartlands in Sweden. The population redistribution behind this type of cluster corresponds well with the overall emigration from these areas, first to colonize the northern part of Sweden and thereafter North America. In the 20th century, the LL-clusters become increasingly mixed up with HL-clusters. It also alternate in a similar way with its centre of gravitation between different parts of southern Sweden. This happened over time during the urbanisation, and it leads us to interpret this is part of the urbanisation not only as a movement of people from the closest surrounding countryside, but also from a countryside at a longer distance to the growing cities.
The last defined spatial dependency, a parish with decreasing population surrounded by parishes with increasing populations (LH-clusters), can also be found, even though it is not that common either in time or space. However in the early 19\textsuperscript{th} century, LH-clusters could be seen in the northern parts of region of Scania in the most southern part of Sweden. Here it corresponds to enclosure revision, the colonisation of locally marginalised and unproductive agricultural land. Furthermore, LH-clusters were observed around the metropolitan city of Stockholm during the urbanisation process.

Even though these clusters of spatial dependencies can be observed to be at work, perhaps the most striking feature in the population redistribution throughout the study period is the lack of statistical significant spatial dependency (on a 5% significance level) and the development over time in this respect is also clear. The share of the parishes where population change does not correlate with surrounding neighbouring parishes increased from 63 per cent in the first sub period to above 93 per cent during the last period at the end of the 20th century. To check the sensibility, we also made the same analysis on the 10% significance level. It turns out that about 55 per cent of the parishes had non-significant correlations with the surrounding parishes in the first sub period and in last sub period it was about 89 per cent. Also the patterns from Figure 3 were more or less reproduced. This means that the spatial relations in the redistribution of the population, as described in the literature, was at work in Sweden during the last 200 years either are counter acting each other, or are at work on an even lower geographical level which is not possible to measure here.

**Spatial-temporal dependency in the local population change**

We first turn to the analysis of the temporal dependencies in the Swedish population redistribution controlling for spatial dependencies. Table 4 shows the time parameter and the interaction parameter from equation 1. As shown in the table, the fitted covariance function was far from 0, and therefore, since the estimated interaction parameter $\beta$ varies between 0.33 and 0.95 (table 4), it shows the importance of including time-space interaction in a non-separable covariance model when analysing population redistribution. The strongest temporal correlation of 0.54 was found for the period of 1840-1880 (Table 4). This shows that during this
period, the population redistribution was heavily dependent on the previous years’ observation. From being very low, the correlation once again increases at the end of the study period. Therefore according to this study, it seems as if time dependency in the local population change is low when the population and the distribution change substantially as it is after the industrial revolution the 1880s and approximately at a time when became a common good in the 1960s.

Table 4. Estimated parameters for temporal changes within parishes.

<table>
<thead>
<tr>
<th>Time period</th>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>Correlation between annual changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1810-1840</td>
<td>0.89</td>
<td>0.33</td>
<td>0.25</td>
</tr>
<tr>
<td>1840-1880</td>
<td>0.02</td>
<td>0.84</td>
<td>0.54</td>
</tr>
<tr>
<td>1880-1930</td>
<td>0.64</td>
<td>0.92</td>
<td>0.06</td>
</tr>
<tr>
<td>1930-1960</td>
<td>0.84</td>
<td>0.95</td>
<td>0.02</td>
</tr>
<tr>
<td>1960-2000</td>
<td>0.62</td>
<td>0.76</td>
<td>0.11</td>
</tr>
</tbody>
</table>

We now turn to the analysis of the spatial dependencies in the Swedish population redistribution controlling for inherent time dependencies. Figure 4 give the correlation in population change between an average parish and other parishes lying with a increasing distance (between 0 and 20 km) from it for a time lag of 0 years (ie $u = 0$) during the different sub periods. This shows that the spatial correlation decreases with increasing distance. In the 19th century the correlation between parishes population change was still as high as about 60 percent when they were as far away from each others as 20 km. At the end of the 20th century the distance decay function is much steeper. The spatial correlation in population change between parishes is on average already non-existing when the distance between them is 5 km. To conclude, spatial dependency has gone from a situation in which there was a strong dependency with parishes located far away from each other to a situation where there is a very limited covariation between parishes as close to each other as 5 km.
CONCLUDING DISCUSSION

In this study, we analyse how local population change is affected by neighbouring populations. To do so we use the last 200 years of population redistribution in Sweden. From the literature several different processes and spatial dependencies can be identified. The analysis is based on a unique unchanged historical parish division, and the methods used are an index of local spatial correlation (Anselin Local Moran’s I). To control for inherent time dependencies we introduce a non-separable spatial temporal correlation model into the analysis of population redistribution.

We found that the correlation between neighbouring parishes’ population change have diminished over time. From a situation in the 19th century when there was a strong spatial dependency even between parishes as far apart as 20 kilometres, it has change so that, nowadays, the correlation is already marginal when the distances between parishes is 5
kilometres. The conclusions that can be drawn from this are: firstly that the local population changes have been rather dependent on the neighbouring populations and secondly spatial dependency in this respect is nowadays very low.

Another finding is that the temporal dependency in the local population change increases when the geographical distribution of population becomes more stable.

We also found several different spatial dependencies at work influencing the redistribution of population. For instance, all local spatial dependencies defined by Local Moran’s I can be observed. In fact it is shown that for most of the time, two or more local spatial dependencies are at work in redistributing the population at the same time. However, which of the four spatial dependencies analysed here that are at work at the same time change over time. Also note that the 4 spatial dependencies defined by Moran’s I (see Table 3) do not capture all the spatial combinations that are at work simultaneously in the redistribution. A mixture of different spatial dependencies at work simultaneously in the same area lends us to add interpretations which combine the defined spatial dependencies. Lastly, the only significant spatial dependencies in the population redistribution in Sweden over the last 40 years can be observed around the three metropolitan areas. The conclusion drawn from this pattern is that the redistribution in Sweden is related to immigration and high fertility rates.

It is sometimes argued that population redistribution is a complex process. To make it understandable, the spatial patterns are often summarized and simplified to a single spatial measure, or to the rural urban dimension, or urban hierarchy, or to a very high geographical level. Further, the inherent time dependency in the redistribution is seldom controlled. The long population redistribution in Sweden is certainly a result of different processes at work creating complex patterns of spatial dependencies. Applied to Sweden, we suggest some methodologies that on a low geographical level are able to both visualize the complexity in the population redistribution and to summarize this when the inherent time dependency is controlled for.
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APPENDIX

To estimate the parameters in the spatio-temporal covariance model we use the variogram function (see Sherman 2011). The variogram is related to the covariance model as 
\[ \gamma(h; u) = \mathcal{C}(0; 0) - \mathcal{C}(h; u) \] 
and simplifies parameter estimation in (1). The variogram can be reformulated as:

\[ \text{var}(Z(s + h; t + u) - Z(s; t)) = 2\gamma(h; u). \]

and consequently a moment estimate of the observed \( \gamma(h; u) \) is:

\[ \hat{\gamma}(h; u) = \frac{1}{2N(h; u)} \sum_{N(h; u)} \{[Z(s_i; t_i) - Z(s_j; t_j)]^2} \]

where \( N(h; u) \) is the number of pairs of observations, truncated at 200 km and ±20 years with no correlation assumed beyond these limits.

The fitting algorithm was implemented in R (www.rproject.org). We minimize the difference between a model variogram \( \gamma \) curve to the observed variogram \( \hat{\gamma} \), where \( \hat{\gamma} = \{\hat{\gamma}(h_1; u_1), \hat{\gamma}(h_2; u_2), ..., \hat{\gamma}(h_m; u_m)\} \) (see Cressie 1993 and Sherman 2011). In doing so we assume that the real parameter of covariance is \( \theta \). For each \( \theta \), \( \gamma(\theta) \) is defined as the value of the m-dimensional variogram. Therefore, the minimization criterion is \( Q(\theta) = \hat{\gamma} - \gamma(\theta) \). The model variogram is then fitted using weighted least square (WLS) (see Sherman, 2011) such that we only need to minimize:

\[ Q(\theta)^T W Q(\theta) = \sum_{i=1}^{m} w_i^2 Q_i^2(\theta) \]

where \( W \) is a diagonal matrix, with elements \( w_i^2 \) on the diagonal. The choice of weight is \( w_i^2 = N(h_i; u_i)/2\gamma^2(h_i; u_i) \), because \( 2\gamma^2(h_i; u_i)/N(h_i; u_i) \) characterize the variance of \( \hat{\gamma}(h_i; u_i) \). Plugging in \( w_i^2 \) the final expression to be minimized is \( \sum_{i=1}^{m} N(h_i; u_i) \left[ \frac{\hat{\gamma}(h_i; u_i)}{\gamma_i(\theta)} - 1 \right]^2 \).

To find estimate \( \theta \), a set of initial combination values between 0 and 1 was given and we implement Nelder–Mead simplex algorithm to find the optimal \( \theta \). To avoid local minimum, we
ended up with 84 thousand different initial value combinations for each period and selected the solution with the minimal function value.