Could the Fertility Decline in Space and Time Just Be a Communication Process? Agent-Based Simulations on Swedish Data

Sebastian Klüsener[*], Francesco Scalone[**] and Martin Dribe[***]

* Max Planck Institute for Demographic Research, Rostock (kluesener@demogr.mpg.de)
** Department of Statistical Sciences, University of Bologna (Francesco.Scalone@unibo.it)
*** Centre for Economic Demography, Lund University (Martin.Dribe@ekh.lu.se)

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Abstract

Fertility decline is often viewed in the framework of innovation and adjustment (Carlsson 1966). According to the innovationist view fertility decline results predominantly from the diffusion of new knowledge, with spatiotemporal variation in the decline being shaped by communication pathways. The adaptationist view understands fertility decline primarily as a result of an adjustment to new circumstances, with spatiotemporal variation in the decline being related to variation in factors fostering the change (e.g. increased infant survival). In this project we analyze individual-level data of the Swedish censuses 1880-1900. We run agent-based simulations under static conditions with no variation in adjustment incentives to explore whether communication processes that are shaped by social and spatial variation in communication links are able to reproduce observed spatiotemporal characteristics of the fertility decline in different social status groups (elite, worker, farmer). Our results show that virtually all major spatiotemporal characteristics of the fertility decline could in principle just stem from communication processes.

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"The nebula-like cluster is a common trait in the spatial picture of man's attributes. Take any atlas showing economic and cultural elements and you will find an endless sequence of spatial distributions which have a concentrated core surrounded by a border zone of outwards decreasing density. There is nothing such as one single and simply explanation [...]. But nevertheless one particular process which creates this type of distribution—temporarily or as an end result—seems to be highly significant: diffusion of techniques and ideas through the network of social contacts"

Torsten Hägerstrand (1965)

Introduction

The decline of fertility in the demographic transition has for a long time been a major theme in contemporary and historical demography. Much of the literature has been focusing on the demographic aspects of the decline aiming to chart the process without actually explaining it. Other research has offered explanations to the decline mainly at the macro level; while much less attention has been given to disaggregated patterns and micro- as well as social interaction analyses. Fertility decline is often viewed in the framework of innovation and adjustment (Carlsson 1966), where the first explains fertility decline as a diffusion of new knowledge or attitudes to fertility control, while the latter sees the decline as a result of an adjustment of behavior to new circumstances and a greater motivation to limit fertility. According to the innovation perspective, fertility before the decline was not deliberately controlled, but "natural" (Henry 1961). Thus, marital fertility was not affected by parity-specific stopping but determined by the length of birth intervals, and these in turn were to a large extent determined by the length of breastfeeding and the level of infant and early child mortality. In this sense, the fertility decline was mainly a result of the innovation of families to start limiting family size by terminating childbearing after having reached a target family size (cf. Coale and Watkins 1986; Cleland and Wilson 1987). The emergence of deliberate birth control involved transmissions of new ideas and changing attitudes and norms concerning the appropriateness of fertility control within marriage. It also involved acquiring knowledge of how to limit fertility. But many believe this knowledge to have been present long before the decline even though it might not have been used for parity-specific control, but for spacing of births or avoiding childbearing in difficult times (see, e.g., David and Sanderson 1986; Santow 1995; Szreter 1996; Van Bavel 2004; Bengtsson and Dribe 2006; Dribe and Scalone 2010).

According to the adjustment perspective, fertility decline is viewed as a response to changes in the motivation of having children. In the theoretical framework outlined by Easterlin and

Crimmins (1985), both the demand and supply of children are important in explaining the high pre-transitional fertility. The supply of children is defined as the number of surviving children a couple would get if they made no conscious efforts to limit the size of the family (Easterlin and Crimmins 1985). Thus, it reflects natural fertility as well as child survival. High mortality in pre-transitional society (low supply) together with a high demand for children implied that demand exceeded supply. Fertility decline is explained by adaption to processes which influenced the demand and/or supply side. This includes reductions in child mortality (Galloway et al. 1998; Reher 1999; Reher and Sanz-Gimeno 2007), as well as changing costs of children, e.g., as a result of economic changes in food and housing prices or of government interventions to limit child labor or to increase the period of schooling. In addition, high costs of fertility regulation lead to a time lag between these changes in demand/supply and children ever born. These regulation costs were at least partly determined by lack of knowledge or negative attitudes towards birth control. Diffusion of new ideas on these matters might, consequently, have contributed to declining fertility in this period. Thus, also processes of adjustment might depend on existing communication links.

Although there is growing empirical evidence for spatial diffusion of new behavior being an important part of the fertility decline (Schmertmann, Assunção and Potter 2010; González-Bailón and Murphy 2013; Goldstein and Klüsener 2014), there has been little research exploring empirically with simulation models how the social connectedness of individuals and places in space might contribute to shape spatiotemporal aspects of the fertility decline. There is also a lack of empirical analyses investigating factors that cause the substantial variation in the spatiotemporal decline pattern in different social classes (see below), although theoretical consideration and research results by Szreter (1996) indicate that such research could deliver very important insights. With this project we aim to contribute to close these existing research gaps.

In our title we posed the question whether the fertility decline in space and time could just be a communication process. It is important to point out that this question is posed in a hypothetical manner, as we believe that the fertility decline is both shaped by innovation diffusion and adaptation to changing circumstances. Thus, it is not our aim to prove with our analysis that the fertility decline is just driven by communication processes. Instead we are aiming to explore which of the major spatiotemporal characteristics of the fertility decline in Sweden in the period 1880-1900 in three different social status groups (elite, worker, farmer) could emerge just through communication processes shaped by social and spatial variation in communication links. This, we hope, will allow us to distinguish those spatiotemporal characteristics of the fertility decline whose explanation would require reference both to communication and adaptation explanations, from those which could potentially just emerge as a result of communication processes. To accomplish this, we use in our simulation models a *ceteris paribus* approach in which we model the fertility decline as a communication process within a static society that is a representative sample of the Swedish population of 1880 stratified by regions, social status and age. In our model there is no spatiotemporal variation in adjustment incentives[1], our agents do not migrate or age. Following Hägerstrand (1965) and Rosero-Bixby and Casterline (1994), we use migration data to derive information on existing communication links between peoples and places. This information we derive at the individual level through attributes on the place of birth and current place of residence of women in childbearing age. This we do for different social groups which we identify via occupational information. We then explore how a fertility decline would emerge in space and time in different social status groups, if it would just be driven by communication processes shaped by social and spatial variation in communication links.

Another motivation for our study is related to a recurring observation in spatial analyses of the fertility decline in various countries. Several studies identified clusters of high fertility decline around early centers of the decline (e.g. big cities), which cannot be explained by socio-economic characteristics of these areas (Schmertmann, Assunção and Potter 2010; Goldstein and Klüsener 2014). These clusters might be caused by diffusion of the adaptation of fertility controlling behavior due to social interaction, or by omitted variables representing socio-economic processes that start to spread out from the centers of the decline as soon as the fertility decline gains momentum in these centers. While conventional regression methods offer little options to explore whether these clusters of the decline might indeed be related to social interaction, our simulation models allow to look into these aspects.

We believe that our study contributes in a number of ways to the debate on factors that shape the fertility decline during the demographic transition. First, to our knowledge we are the first aiming to model the fertility decline in space and time for different social status groups with simulation models. Second, our models will allow us to explore whether the spatial clustering of fertility decline around early centers of the fertility decline might indeed be shaped by social interaction processes. Third, our emphasis on trying to disentangle characteristics of the fertility decline that could be solely caused by communication processes from those which

[1] The excluded adjustment incentives include not only variation in infant mortality and socioeconomic factors directly affecting the costs of children. They also comprise variation in social norms that, for example condemn the use of contraceptive techniques. The latter might create indirectly costs as in areas in which such social norms are wide-spread, persons that adopt a fertility controlling behaviour might face losses in their social capital, which Bourdieu and Wacquant (1992, p. 119) define as the resources that “accrue to an individual or a group by virtue of possessing *a durable network of more or less institutionalized relationships* of mutual acquaintance and recognition.” Losses in social capital might also have repercussions on future income opportunities.

require also reference to adaptation processes might particularly be of relevance for discussions on the prospects of fertility decline in low developed countries in Africa. In the latter the low pace of development might create little adaptation incentives for adopting fertility controlling strategies. But if the fertility decline is indeed predominantly driven by communication processes, it might also spread fast in these societies once a specific threshold of early adaptors has been reached.

Theoretical Considerations

As our agent-based simulations will focus on exploring the potential role of communication processes in the diffusion of the fertility decline, we will restrict ourselves in the theoretical section to considerations on the interplay between space and social status in communication processes. For a more detailed account how space and place might affect both spatial variation communication diffusion and adaptation incentives see Klüsener, Scalone, and Dribe (2013).

Under the assumption that diffusion processes are important for the fertility decline, it is relevant to mention that most of the social interaction in our study period was still local in character. Therefore, it is likely that in the diffusion of the adaptation of this new behavior spatial distance was acting as an important constraint. Thus, in the initial phase of such a process the diffusion is most intense inside localities were pioneers have already adopted the behavior, and in areas that are either geographically adjacent to these early centers of fertility decline or closely connected to them as a result of high communication intensities. Aspects of spatial dependency in social interaction might cause a spatial decline pattern that Hägerstrand (1965) referred to as nebula cluster.

Big cities act as important communication and transport hubs, an aspect which is also supported by our empirical analysis. Thus, these places might not only emerge as early centers of the fertility due to an increased adaptation pressure as a result of higher costs of children or a wider variety of social mobility option, but also because information with relevance for the adaptation of a fertility controlling behavior is more likely to reach inhabitants of the cities very early. This might particularly be true for capital cities, which are linked to other capital cities due to the diplomatic corps and their communication. At the time when the fertility decline in Sweden started only France and parts of Belgium had already witnessed a substantial fertility decline. If it spread to Sweden from these two countries, Stockholm and other big cities were potentially most exposed to these new ideas at the had the highest density of communication links (see below).

In many studies of fertility decline elite groups have been identified as early adopters (Livi Bacci 1986, Haines 1992). Theoretical explanations for this might be linked to distinctive characteristics of elites. We already mentioned that at least in historic times, elite groups were most likely to maintain social networks across long distances which contributed to a better access to information. These social networks could comprise (kin-) relationships and contacts between members of similar higher-level professions living in different cities (Szreter 1996). Extensive social networks might also have developed by visiting one of the few higher education institutions or as part of a service in the higher ranks of the military. Evidence for elites of the same profession having very similar fertility trends, even if they lived in distant places, has been presented by Szreter (1996) in his seminal study on socio-economic differentials of the fertility decline in Britain. Based on his study he argued that "communication communities" of similar social background are very important to understand the mechanisms of the fertility decline process. These considerations were of high relevance for the specification of our agent-based simulations.

Data

For our study we use micro-level data from three Swedish censuses (1880, 1890 and 1900), which were digitized by the Swedish National Archives and are about to be published by the North Atlantic Population Project (NAPP). The latter adopts the same format as the Integrated Public Use Microdata Series (IPUMS) (Ruggles et al. 2011). In total, the 1880 census counts about 4.6 million persons in 1.2 million households, while the corresponding figures in the 1890 and 1900 censuses are 4.8/1.3 and 5.2/1.4 million, respectively. All registered individuals are grouped by household. In this way, each individual record reports the household index number and the person index within the household. The parishes of residence and birth, age, marital status and sex of each person are also registered. A person's relationship to the household head is recorded as well. In addition, there are family pointer variables indicating the personal number within the household of the mother, father, or spouse, making it possible to link each woman to her own children and husband.

The census data is linked to a historical GIS-file of Swedish administrative boundaries which has been set up by the Swedish National Archives. It provides the boundaries of all parishes that ever existed in Sweden since 1638. From this dataset we constructed a GIS-file with parishes of time-constant areas for the period 1880-1900 (N=2,435). Next to the parish level, we can also consider three higher levels of administrative division: districts and cities (N=372), judicial districts and cities (N=159) and regions (N=25). This provides us high flexibility in the choice of the spatial detail at which we carry out our analyses and simulations.

The census datasets offer detailed information on occupation, allowing a classification into a fairly large number of social groups using the Historical International Standard Classification of Occupations (HISCO) system (Van Leeuwen et al. 2002). Based on this categorization we then differentiate 12 different social classes using the HISCLASS system (Van Leeuwen and Maas 2011). This is an international classification scheme based on skill level, degree of supervision, type of work (manual vs. non-manual), and whether residence was in an urban or rural area. The classification system contains the following classes: 1) Higher managers; 2) Higher professionals; 3) Lower managers; 4) Lower professionals, clerical and sales personnel; 5) Lower clerical and sales personnel; 6) Foremen; 7) Medium skilled workers; 8) Farmers and fishermen; 9) Lower skilled workers; 10) Lower skilled farm workers; 11) Unskilled workers; and 12) Unskilled farm workers. To avoid problems of small number of observations in some classes we consider further aggregated classification schemes based on six or three groups. In the classification based on six groups we differentiate as follows: Elite and upper middle class (HISCLASS 1-6), Skilled workers (HC 7), Farmers (HC 8), Lower skilled workers (HC 9-10), Unskilled workers (HC 11-12). In the classification based on three groups we consider the following division: Elite (HC 1-6), Farmers (HC 8), Workers and other social groups (HC 7, 9-12). As many women did not provide occupational information in the census, we decided to derive the social status via the occupation of the husband. This implies that we can only derive social status information for women where the spouse was present at the time of the census.

Analytical Strategy

Before we turn to the description of the conceptual consideration for the agent-based simulation models, we will first present descriptive results on spatiotemporal aspects of the fertility decline in different status groups in Sweden between 1880-1900. This descriptive analysis will be instrumental for identifying major characteristics of the fertility decline pattern that we attempt to reproduce with our simulation models. In addition, the descriptive analysis will also be important to derive assumptions for our simulation models. The descriptive findings section is followed by the conceptual considerations and outcomes of the agent-based simulations, in which we will try to reproduce the characteristics of the decline with communication processes based on simple communication rules. In this simulations we test different scenarios related to the start of the fertility decline in Sweden.

Descriptive Analysis of the Fertility Decline in Space and Time in Sweden 1880-1900

For the descriptive analysis of the spatiotemporal fertility decline pattern we face the problem that census data do not permit the computation of standard fertility rates (ASFR, TFR, etc.). Thus, we use an indirect measure of fertility called the child-woman ratio (CWR). The CWR has been traditionally defined as the number of children aged 0-4 per woman aged 15-49 (Shyrock and Siegel 1980). We are able to use this measure at the individual level, which implies that the children under five may have been born during the five-year period before the census date, where the mother was up to five years younger. To ensure that we capture recent net marital fertility, we only use own children under five and limit the sample to currently married women with spouses present. Thus, we create a sample of married women aged 15-54 from the three censuses to make sure that all children 0-4 to women 15-49 are included. Descriptive statistics of these samples are presented in Table 1.1 (see appendix). In total we have about 600,000 married women in each census. We assume that results of an analysis of marital fertility, if available, would be very similar to our analysis of net marital fertility. A comparison of net fertility (child-woman ratios) and marital fertility (based on the own-children method using SES-specific mortality data) for Malmöhus county in Sweden 1896-1900 indicates very similar results by social class (Scalone and Dribe 2012). Although unadjusted child-woman ratios were underestimated for high mortality groups in relation to low mortality groups, the relative positions of the different socioeconomic groups were the same for the adjusted and unadjusted child-woman ratios. Net fertility might also be a more informative measure of fertility as we expect the number of surviving children to be what families cared about, rather than the number of births. Even though some of the fertility transition came about to offset lower mortality (Galloway et al. 1998; Reher 1999; Reher and Sanz-Gimeno 2007; Dyson 2010), it is important to see that the decline in net fertility was more important in the long run, as it exceeded by far the adjustments for mortality improvements (Doepke 2005).

Table 1 Number of children 0-4 (Child-woman ratios) by socioeconomic status

	1880	**1890**	**1900**
SES			
Elite	**0.87**	**0.82**	**0.73**
Farmers	**0.85**	**0.85**	**0.83**
Workers	**0.89**	**0.93**	**0.90**
NA	**0.75**	**0.73**	**0.74**
Total	**0.87**	**0.89**	**0.85**

Source: Micro-level census data, SweCens, The Swedish National Archives

In Table 1 we show the child-woman ratios by socio-economic status in the three censuses. Overall, net fertility declined by about five per cent between 1890 and 1900, but actually increased somewhat between 1880 and 1890. This increase could be related to infant and child mortality declining faster than fertility levels, as aggregate total fertility actually also declined in this period (Dribe 2009). However, the trends differ substantially by social class. While the upper and middle classes experienced declines of around 17 per cent in net fertility between 1880 and 1900, unskilled workers instead reported an increase of three per cent over the same period.

The trends also substantially vary across space, as can be seen in the maps displaying spatial aspects of (net) fertility trends by social class (Figure 1). Figure 1a shows for all women the changes in the child women ratio between 1880 and 1900, while the Figures 1b-1d display the pattern differentiated by the three social class categories (elite; farmer; worker and other). We map the decline at the level of the judicial districts. Cities that formed own judicial districts and had more than 5,000 inhabitants in 1900 are highlighted with circles which vary dependent on the number of women aged 15-49 in a particular social class. The map providing the trends for all women independent of their social class shows a pattern, which resembles to some degree Hägerstrand's (1965) description of a nebula-like cluster. This pattern is very typical for cartographic representations of the fertility decline as part of the demographic transition (see e.g. the Princeton Maps in Coale and Watkins 1986; Schmertmann, Potter and Cavenaghi 2008; Goldstein and Klüsener 2014). The decline was concentrated on big centers such as Stockholm and Malmö[2], surrounding areas and central transport and communication corridors. This includes the lake area in central Sweden between Stockholm and Gothenburg.

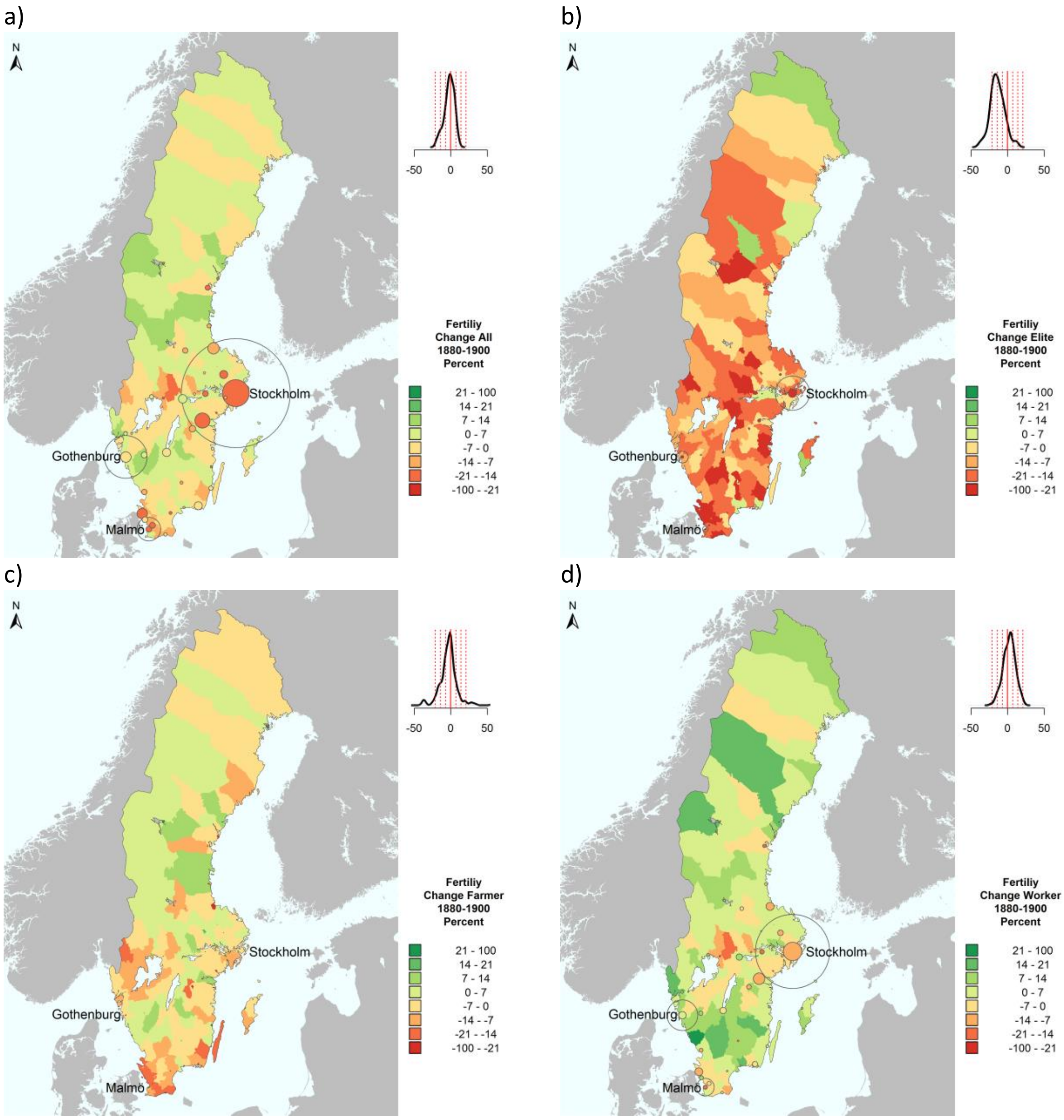
If we look at the pattern for the elite (Figure 1b), we see, however, a very different picture. In almost all areas of Sweden elite women experienced a decline independent of whether the area was remote or central. Yet, the areas with the highest decreases are concentrated in the southern half of Sweden, while the north experienced lower reductions. Overall does the decline pattern of the elite suggests that ideas on the advantages of reducing fertility and technologies to prevent conceptions or births had at that period already spread to virtually all parts of Sweden.

The spatial fertility change pattern of the farmers resembles closely the one for all social groups. This could be expected as farmers were the predominant social class in rural areas which covered most of Sweden at that time. The situation is different for our social class of workers. Women of this group actually experienced in the period 1880 to 1900 in many parts of Sweden increases in the CWR. This even includes the city of Gothenburg and the city of Stockholm in the period 1880-1890 (see below). However, in both cities the trend was reversed in the period 1890-1900, with the decline in Stockholm being so strong that the 1900 levels submerged the ones of 1880. Malmö registered declines in both sub-periods, but wit-

[2] With regard to Malmö it is important to note that it is located close to the Danish capital of Copenhagen, which was at the end of the 19th century the biggest city in Scandinavia. Copenhagen entered the period of drastic fertility decline around 1880 (Coale and Watkins 1986).

nessed an acceleration in the decline after 1890. Overall, the maps of Figure 1 provide the impression that the fertility trends varied substantially by social class in this early period of the Swedish fertility decline. This provides support to the communication communities hypothesis by Szreter (1996).

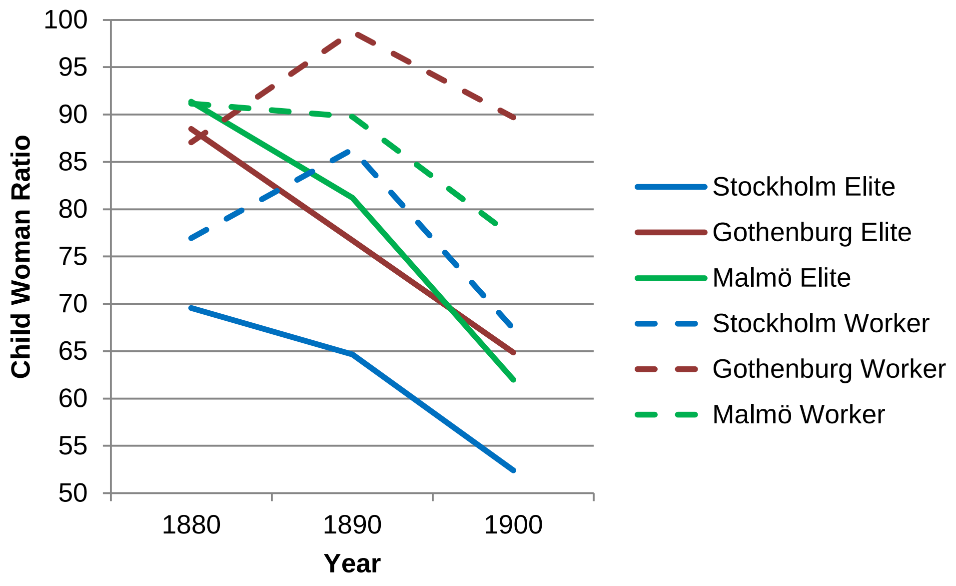
Fig. 1 Changes in Child-Woman Ratio



Source: Micro-level census data, SweCens, The Swedish National Archives.
Base Map: Swedish Parish Map by Swedish Archive, MPIDR Population History GIS Collection

Related to the role of social class differences we detected that in many locations of Sweden the net fertility of some social classes was still rising while the net fertility of the elite was already falling. This is even true for the two biggest cities Stockholm and Gothenburg in the period 1880-1890 (see Figure 2). Overall the descriptive results indicate that at least for the elite group the diffusion of the adaptation of deliberate fertility control strategies was little constrained by absolute spatial distances. Social status differences between individuals living in the same location, on the other hand, seem to have played a substantial role as constraining factor at least in this early phase of the decline. This might be different in later phases of the decline, when this process had already diffused to all social classes.

Fig. 2 Fertility Changes in the Centers of the three Biggest Swedish Cities by Social Status



Source: Micro-level census data, SweCens, The Swedish National Archives.

Conceptual Considerations on the Agent-Based Simulations

The main aim of our agent based simulations is to explore whether we are able to reproduce with simulated communication processes that are shaped by social and spatial variation in communication links major spatiotemporal characteristics of the observed fertility decline in different social status groups (elite, worker, farmer). Based on our descriptive findings and the existing literature, the following characteristics are in the main focus of our attention.

- Members of the elite should be the forerunners in the process particularly in the early part of the decline. A potential mechanism might be the high number of communication links elite people had across Swedish regions and particularly with the capital city Stockholm, which was an early centre of the fertility decline in Sweden. Thus, elite member were perhaps more likely to be exposed very early to the idea to adopt fertility controlling strategies. Szreter (1996) referred to these aspects as "communication communities". These considerations are also supported by migration matrices for women of childbearing age which we present in appendix 1. They show that elite women were at least in terms of net-migration links between place of birth and place of residence much more linked through Sweden compared to workers and farmers.

- Farmers, on the other hand, should be laggards in the decline, with a potential mechanism being that members of this social group do not have many communication links across long distances (see also appendix 1).

- Workers should not adopt as fast as the Elite also as they have usually less communication links with the capital. However, in terms of communication processes they might catch up later with the Elite as soon as the idea of a fertility controlling strategy has started to spread in highly industrialised regions.

- Big cities and particularly Stockholm city and Malmö should be early centres of the decline with a potential mechanism being their role as communication hubs.

- The peripheral far North of Sweden should lag behind in the decline.

- Elite groups should experience the decline rather homogenously across space as they often communicate across long distances (Szreter 1996), while the decline of farmers should particularly in the beginning cluster around early centres of the decline (e.g., big cities).

In our simulation models we include only married women in childbearing age[3] with spouse being present[4] The agents are a representative sample of this group within the Swedish population in 1880, which marks approximately the start of the large scale fertility decline in Sweden (see Coale and Watkins 1986). The sample is stratified by the 25 regions (*laens*) and three social status groups (elite, farmer, worker, based on HISCLASS). In most of our models we work with sample sizes between 10% and 30%. Next to the place of residence and social status we also consider in some models the age of the women categorized in six age groups (20-

[3] In contrast to our descriptive analysis, we excluded married women below 20 and above 49 as we want to run the simulation models in some instances separately by five-year age groups. In these cases we wanted to avoid the challenge that the number of married women in the age groups 15-19 and above 49 is rather small causing a lot of fluctuations.

[4] In order to derive the social status via the occupation information of the spouse.

24,25-29,30-34,35-39,40-44,44-49). As proxy for communication links the ABM uses information on life-time net migration links measured by place of birth and place of residence of women in childbearing age (following Hägerstrand 1965; Rosero-Bixby and Casterline 1994). We also have information on children under aged 1 that are linked to the women via the mother locator attribute. This information we will use in scenarios in which we attempt to derive estimates on the share of women that already adopted fertility controlling strategies from recent fertility events (see below).

For the simulation models we divide the agents up into groups by region of residence (N=25), social status (N=3) and in some cases in additional by age (N=6). Thus, we are either considering 75 groups or if we further subdivide by age 450 groups. In the models we do not attempt to model full fertility histories of agents as we have from the census only information on surviving children so that estimates on fertility rates for different ages and social classes across regions would need to be based on very bold assumptions. Instead, we decided to focus on the process of adaptation of a fertility controlling behaviour. Following González-Baillon and Murphy (2013) in their ABM of the fertility decline in France, this adaptation of fertility controlling behaviour is modelled as an irreversible process. Once adopted, a women sticks to this behaviour. The population of agents is static and neither ageing nor migrating. This allows us to simulate a fertility decline process which is just influenced by the starting conditions and social and spatial variation in communication links.

For the model to run there must be at least one agent in the population who has already adopted the new behaviour. In creating the starting situation t_0 for the ABM, two approaches are considered. In the first approach early adopters are defined based on different assumptions how the process might have started (e.g., random origins, diffusion of ideas from early decline countries, start of the decline in big cities). In the second approach we attempted to obtain estimates on the share of adaptors in each of the 450 groups from the 1880 census dataset. Detailed descriptions of the scenarios and how we derived the estimates are given further below. As communication pathways three potential mechanisms are considered:

Social adaptation:
In this variant of the simulation model the risk of adoption in is influences by the share of women who have already adopted the behaviour. Each time period all women that have not adopted fertility controlling behaviour are at risk to adopt. For each woman who has not adopted a random number between 0 and 1 is generated. If the number is above

$$(1)\ 1-(SAR*w+SAB*(1-w)/1000$$

with SAR denoting the share of adaptors in the region of residence, while SAB represents the share of adaptors in the region of births. W is a weight between 0 and 1 that denotes the relevance that is given to the share of adaptors in the region of residence in comparison to the share of adopters in the region of birth. Thus, the risk to adopt a fertility controlling behaviour lies between 0 (in case the share of adopters in the place of birth and place of residence is 0%) and 0.1 (in case the share of adopters in the place of birth and place of residence considered is 100%). Currently, it is assumed that women only copy behaviour from women of similar social status and age in their place of birth and place of residence. In an extension it would be also possible to implement communication rules in which women copy behaviour from women of other SES or age, but with a lower likeliness.

Social influence:
In this model variant women who have already adopted a fertility controlling behaviour act as agents of change. Each time period for each woman who has already adopted fertility controlling behaviour two random numbers between 0 and 1 are drawn. The first determines based on a threshold (e.g. number above 0.95) an interaction with a randomly determined women in the region of residence, in which this other women is convinced to adopt fertility controlling strategies, in case she has not yet adopted such strategies. The second determines a similar interaction with a randomly determined women in the region of birth. The advantage of this model variant is that it allows interactions where e.g. agents who have moved out from villages to big urban centres communicate new ideas to persons who have remained in their home region (sisters, friends). These interactions could not be captured by the social adaptation specifications, where women that have remained in their birth region could only be influenced by what is happening in this region.

Social learning:
In this model variant women who have not adopted fertility controlling behaviour are copying behaviour from forerunners. Each time period for each woman who has not yet adopted a fertility controlling behaviour two random numbers between 0 and 1 are drawn. The first determines based on a threshold (e.g. number above 0.95) an interaction with a randomly determined women in the region of residence. If this other women has already adopted fertility controlling strategies, the interacting agent adopts. The second determines a similar interaction with a randomly determined women in the region of birth. Such a copying of behaviour might have occurred more frequently than a women convincing other women to adopt as we assumed in the social influence variant of the model- However, a disadvantage of this social learning mechanism is that women can only learn from women in their region of residence if they are still living in their region of birth.

In the first approach that tests different scenarios, the following scenarios are considered:

- **Random start scenario**: In the random start scenario a set of early adopters are randomly chosen independent of their place of residence within Sweden and their social status. This simulation explores whether the existing communication links would allow a self-organisation of the fertility decline process from complete randomness just based on some simple communication rules. As particularly the elite has strong links to the city of Stockholm from all regions of Sweden, the process might have the tendency to spread fast among the elite to Stockholm city and from there to the rest of the country.

- **Diffusion from early decline countries scenario**: In this scenario it is assumed that the idea to adopt fertility controlling behaviour comes into Sweden through communication links with other countries where this behaviour is already wide-spread. Around 1880 only two European countries had witnessed substantial fertility declines. These were France and the French-speaking part of Belgium. In this scenario we thus assume that the idea is transported in by women that were born in these two countries (also here we consider only women aged 20-49 with husband present). As these women are particularly concentrated in the capital and big cities and predominantly members of the elite, the process might first cluster in big cities and among elite members.

- **Diffusion from big urban centres scenario**: In this scenario it is assumed that big urban centres are early centres of the decline as populations were either facing the highest economic pressure to adopt or as populations in big urban centres were more open to new ideas. In this scenario the share of adopters in the big urban centres are set to a certain threshold at the beginning of the process. This scenario should be particularly well suited to study the role of communication in generating hot spot clusters of decline which in many countries emerged around early centres of the decline and along communication corridors.

For the second approach we derived crude estimates on the share of adopter in 1880 in the 450 groups from the 1880 census data. For the estimates we obtained national-level decennial age-group specific marital fertility rates for the period 1871-1940 from the demographic yearbooks of Sweden. It is assumed that the average rates for the period 1871-1880 can be considered as pre-transitional fertility rates for all SES. As post-transitional rates the average rates for the 1930s and 1940s are taken. In order to derive the share of adopters, another strong assumption is that women who have not adopted a fertility controlling strategy follow the pre-transitional fertility schedule as recorded in the 1870s, while women who have adopted such a strategy follow the schedule as reported in the 1930s and 1940. We then derive rough estimates for the age-specific fertility rates for the 450 groups in 1880 from the 100% sample of the 1880 census. For this we use information on the children below one, working with a very crude adjustment for infant mortality losses. In terms of regional variation we benefit from the fact that migration rates for women with children under 1 are very low. The share of adjusters in 1880 is derived for each group i via the following formula:

$$(2)\ SAD_g = \frac{(ASMFR_{pre} - ASMFR_g)}{(ASMFR_{pre} - ASMFR_{post})} * 100$$

in which SAD denotes the share of adopters in a specific group g (e.g. elite women of age 20-25 in Region Gotland), ASMFR the age-groups specific marital fertility rate for that age group in Sweden before (pre) and after the transition (post). ASMFR g are the estimated age-group specific fertility rates that we obtain for that group from the 1880 census. Apart from that quite high rates of adaptation for workers and farmers are obtained, the derived pattern look plausible with adoption rates being already particularly high in big cities.

Results

In the presentation of first tentative results of our simulation models we will focus on the outcomes of our diffusion from big cities scenario. The results of models based on this scenario are very similar to our diffusion from early decline countries scenario and the model specification based on our crude estimates on the share of adopters in different groups in 1880. In the diffusion from big cities scenario we assume that the fertility decline started in big cities where the pressure for adaptation was probably highest and people were more open and exposed to new ideas. That the fertility decline started in big cities, is a realistic assumption as particularly the cities of Stockholm and Malmö were forerunners in the decline (see Fig. 1). For this simulation model we set the share of adopters in t_0 in Stockholm city in all 18 groups (3 social classes *6 age groups) to 10%. The women that constitute these 10% of the agents that had already adopted were randomly chosen without taking other attributes in account[5]. To assume that elite, farmers and workers have the same share of adopters in t_0 is rather unrealistic as we are aware that the elite groups experienced the decline in the big Swedish cities much earlier compare to the workers (see Fig. 2). However, the same share of adopters for all social classes and ages was chosen as otherwise a faster adaption rate among the elite might

[5] As an alternative one could determine the likeliness that a women has adopted fertility controlling strategies based on her recent fertility history determined by children linked to that women by mother locator.

stem from choosing a higher share of adopters in this group in the big cities in t_0. Next to Stockholm city the share of adopters in Malmö and Gothenburg and Stockholm regions is set for all of their 18 groups to 5%. Stockholm region was included as there are hardly any farmers living in Stockholm city itself. Thus in order for the process to spread out of Stockholm region for farmers with a sufficient speed the decision was taken to also include Stockholm region as an origin region of the decline.

In Appendix 2 (A2) we present outcomes for a simulation model based on this specification. The outcomes are very robust to which of the different communication mechanism we consider (social adaptation, social influence, social learning). The presented results are based on the social adaptation specification in which the agents are at risk of adopting fertility controlling strategies dependent on the share of adopters in the region of birth and the region of residence[6]. In A2a we show the development of the share of adopters in the three different social classes by displaying the development of the mean value for the 25 Swedish regions. It provides the expected result that the elite experiences a much faster diffusion process compared to the worker and the farmers. The elite seems to be particularly at an advantage in the very early stage of the process as their dense network of communication links across Sweden allows the process to spread fast to all regions. This is also visible in A2b were we show the differences between the share of adopters in the elite group in comparison to the workers and the farmers. Particularly the farmers are substantially lagging behind in the process, while workers manage rather fast to enter a catch-up a process in which they are able to reduce the differences to the elite.

In A2c and A2d we provide information on the development of regional variance in the share of adopters based on two dispersion measures (coefficient of variance and standard deviation). Also these outcomes are in line with our expectations that the strong connectedness of the elite through space allows them to have a much more homogenous fertility decline pattern compared to the workers and the farmers. This is also visible in the maps A2e1-A2e3 that show the simulated decline pattern for the different social groups. While the elite displays a rather homogenous decline pattern which resembles closely with the observed pattern shown in Fig. 1b, we see for the farmers a strong clustering of the decline in the areas around the big cities. The pattern for the workers (A2e3) deviates most strongly from the observed pattern (Fig. 1d). We believe that this is an artefact of our decision to start the process with similar share of adopters for elite, farmers and workers, although we know that the workers lagged

[6] We give in this specification the birth region and the region of residence a weight of 0.5 (see equation 1). We also tried other combinations such as 0.3 for the birth region and 0.7 for the region of the residence, Reducing the weight given to the birth region results in a more spatially clustered decline pattern, but does not alter our general observations.

behind in the onset of the fertility decline. The maps also fulfil our criteria that the peripheral Northern part of Sweden should lag behind in the process.

Discussion and Conclusion

This first tentative results of our simulations suggest that many of the spatiotemporal characteristics of the fertility decline pattern in the different social status groups can be reproduced with simulation models that model the decline as a diffusion process with simple communication rules using information on social and spatial variation in communication links. In the presented scenario we assumed that the process started in big cities, whose role as early centres of the decline might strongly be related to higher adaptation pressure. However, in our spread from early decline country scenario we obtained similar results when we let the process diffuse from French and Belgian women in Sweden. Also in this case the big cities came out as early centres of the decline as these foreign women were particularly concentrated in the elite groups of these cities. Thus, in case the process indeed diffused from early decline countries into Sweden, the better connectedness of big cities with this countries seems to be substantial enough to let them emerge as early centres of the decline even if population in big cities would face the same adaptation incentives as populations in more peripheral areas.

With our random start scenario in which we let the decline diffuse from randomly chosen agents we were on the other hand not able to produce meaningful decline pattern. As the elite is strongly connected with Stockholm city (See Appendix 1a) the process is likely to spread fast to Stockholm city among the elite, but not fast enough to make Stockholm the centre of the decline. The fertility decline of farmers would also not cluster around cities and transport corridors. In order to produce a pattern with the fertility decline first clustered on urban centres one would need to include additional rules making city inhabitants more open to adopting such a behaviour compared to rural inhabitants e.g. due to higher adaptation pressure or lower uncertainty about potential social consequences as a result of the higher anonymity of cities. However, that we are not able to reproduce a meaningful pattern with the random start scenario is not speaking against our considerations, as we do expect the fertility decline to be a process that emerged out of random origins from some peripheral region in Sweden.

In interpreting the outcomes of our simulation models it is important to point out that communication links created by migration decisions are also shaped by processes of socio-economic change and nation-state building. Thus they might also serve to some degree as a proxy for these processes. It is also likely that migration pattern have influences on spatial variation in social norms as populations with a low share of in-migrants might be less open to change compared to population with a high share of migrants. Nevertheless, our results suggest that even in a static society with no temporal, spatial and social variation in adaptation pressure typical fertility decline pattern can emerge as a result of diffusion of ideas structured by social and spatial variation in communication links. In addition, we were able to reproduce particularly for the farmers typical diffusion clusters around early centers of the decline which are frequently observed in spatial analyses of the fertility decline.

Our findings might be of relevance for low developed countries which are yet at the beginning of the fertility transition, as they suggest that even under conditions of slow socioeconomic development the fertility decline might spread relatively fast once a certain number of early adapters in different social status group have adopted the new behavior. In addition, the outcomes might be of relevance for studies investigating demographic change processes that are likely to be shaped by a mixture of communication processes and adaptation to new circumstances. In recent periods such processes might comprise the spread of cohabitation or the diffusion of gender egalitarian norms in terms of the household division of labor. In case these processes are predominantly driven by communication processes, they are still likely to be structured along social and spatial variation in communication links that emerged also as a result of socio-economic and other processes. In such cases, it is very difficult to differentiate analytically whether the behavioral change process is directly caused by the socio-economic factors that have structured the links or whether it is just making use of the communication links and has no direct relationship to the factors that contributed to create these communication links.

As a next step we plan to run consistency checks to further validate our findings. We particularly have to investigate to what degree the outcomes of our simulation models are not only shaped by social and spatial variation in communication links, but also by variation group sizes. The elite groups have usually much smaller number of agents compared to the farmer groups. If for example in one elite group of 10 persons one person adopts a fertility controlling behaviour, the share of adaptors goes up to 10%. If among a group of 1000 farmers one person adopts, on the other hand, it would just go up to 0.1%. Thus, fast adaptation patterns among the elite might be driven by the fact that the random adaptation of just one person substantially increases the risks of the other members of the group to adopt the behaviour as well. We will look into these effects by working with unrealistic populations in which elites, farmers and workers have similar group sizes and are just representative of the real SES groups in terms of the migration links.

References

Bengtsson, Tommy and Martin Dribe. 2006. Deliberate control in a natural fertility population: Southern Sweden, 1766-1864. *Demography* 43(4): 727–746.

Bourdieu Pierre and Loïc J.D. Wacquant. 1992. *An Invitation to Reflexive Sociology*. Chicago: University of Chicago Press.

Carlsson, Gösta. 1966. The decline of fertility: Innovation or adjustment process. *Population Studies* 20(2): 149–174.

Cleland, John and Chris Wilson. 1987. Demand theories of the fertility transition: An iconoclastic view. *Population Studies* 41(1): 5–30.

Coale, Ansley J. and Susan C. Watkins. (eds.). 1986. *The Decline of Fertility in Europe. The revised Proceedings of a Conference on the Princeton European Fertility Project*. Princeton: Princeton University Press.

David, Paul A. and Warren C. Sanderson. 1986. Rudimentary contraceptive methods and the American transition to marital fertility control, 1855-1915. In: Stanley L. Engerman and Robert E. Gallman (eds.). *Long-Term Factors in American Economic Growth*. Chicago: University of Chicago Press, 307-390.

Doepke, Matthias. 2005. Child mortality and fertility decline: Does the Barro-Becker model fit the facts? *Journal of Population Economics* 18(2): 337–366.

Dribe, Martin. 2009. Demand and supply factors in the fertility transition: A county-level analysis of age-specific marital fertility in Sweden, 1880–1930. *European Review of Economic History* 13(1): 65–94.

Dribe, Martin and Francesco Scalone. 2010. Detecting deliberate fertility control in pre-transitional populations: Evidence from six German villages, 1766-1863. *European Journal of Population* 26(4): 411–434.

Dyson, Tim. 2010. *Population and development. The demographic transition*. London: Zed Books.

Easterlin, Richard A. and Eileen C. Crimmins. 1985. *The Fertility Revolution. A Supply-Demand Analysis*. Chicago: The University of Chicago Press.

Galloway, Patrick R., Ronald D. Lee, and Eugene A. Hammel. 1998. Infant mortality and the fertility transition: Macro evidence from Europe and new findings from Prussia. In: Mark R. Montgomery and Barney Cohen (eds.). *From Death to Birth: Mortality and Reproductive Change*. Washington, D.C: National Academy Press, 182–226.

Goldstein, Joshua R. and Sebastian Klüsener. 2014. Spatial analysis of the causes of fertility decline in Prussia. *Population and Development Review* 40(4): 497-525.

Gonzáles-Bailón, Sandra and Tommy E. Murphy. 2013. The effects of social interactions on fertility decline in nineteenth-century France: An agent-based simulation experiment. *Population Studies* 67(2): 135-155.

Haines, Michael R. 1992. *The European experience of declining fertility, 1850-1970: The quiet revolution*. Cambridge: Blackwell.

Hägerstrand, Torsten. 1965. A Monte Carlo approach to diffusion. *European Journal of Sociology* 6(1): 43–67.

Henry, Louis. 1961. Some data on natural fertility. *Biodemography and Social Biology* 8(2): 81–91.

Klüsener, Sebastian, Francesco Scalone and Martin Dribe. 2013. Social vs. Spatial Distance in the Diffusion of the Fertility Decline: Evidence from Sweden 1880-1900. Paper presented at the IUSSP in Busan, South Korea.

Livi-Bacci, Massimo. 1986. Social-group forerunners of fertility control in Europe. In: Ansley J. Coale and Susan C. Watkins (eds.). *The Decline of Fertility in Europe*. Princeton: Princeton University Press, 182–200.

Reher, David S. 1999. Back to the basics: mortality and fertility interactions during the demographic transition. *Continuity and Change* 14(1): 9–31.

Reher, David. S. and Alberto Sanz-Gimeno. 2007. Rethinking historical reproductive change: Insights from longitudinal data for a Spanish town. *Population and Development Review* 33(4): 703–727.

Rosero-Bixby, Luis and John B. Casterline. 1994. Interaction Diffusion and Fertility Transition in Costa Rica. *Social Forces* 73(2): 435-462.

Ruggles, Steve, Evan Roberts, Sula Sarkar and Matthew Sobek 2011. The North Atlantic Population Project: Progress and prospects. *Historical Methods* 44(1): 1–6.

Santow, Gigi. 1995. Coitus interruptus and the control of natural fertility. *Population Studies* 49(1): 19–43.

Scalone, Francesco and Martin Dribe. 2012. Socioeconomic status and net fertility in the demographic transition: Sweden in 1900 – A preliminary analysis. *Popolazione e storia* 2010/2.

Schmertmann, Carl P., Renato M. Assunção and Joseph E. Potter. 2010. Knox meets Cox: Adapting epidemiological space-time statistics to demographic studies. *Demography* 47(1): 629–650.

Schmertmann, Carl P., Joseph E. Potter and Suzana M. Cavenaghi. 2008. Exploratory analysis of spatial patterns in Brazil's fertility transition. *Population Research and Policy Review* 27(1): 1–15.

Shyrock, Henry S. and Jacob S. Siegel. 1980. *The Methods and Materials of Demography* . Washington, D.C.: U.S. Department of Commerce, Bureau of Census.

Szreter, Simon. 1996. *Fertility, Class and Gender in Britain 1860-1940*. Cambridge: Cambridge University Press.

Van Bavel, Jan. 2004. Deliberate birth spacing before the fertility transition in Europe: Evidence from nineteenth-century Belgium. *Population Studies* 58(1): 95–107.

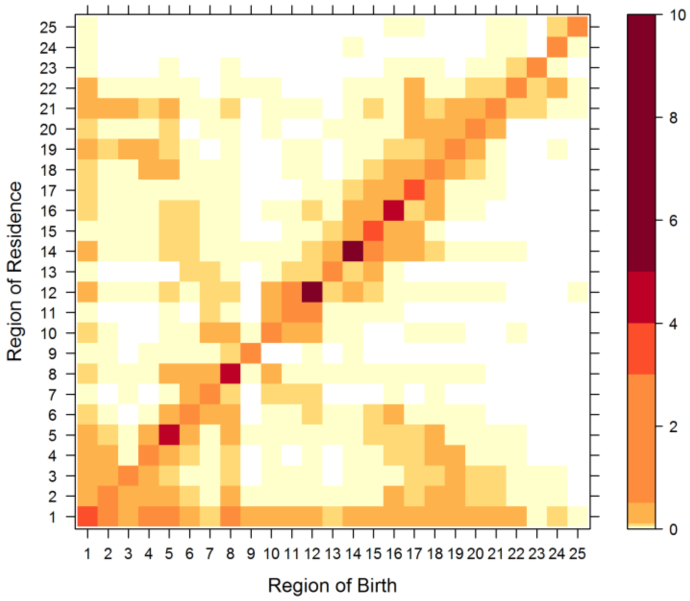
Van Leeuwen, Marco H.D. and Ineke Maas. 2011. *HISCLASS. A Historical International Social Class Scheme*. Leuven: Leuven University Press.

Van Leeuwen, Marco H.D., Ineke Maas and Andrew Miles. 2002. *HISCO: Historical International Standard Classification.* Leuven: Leuven University Press.

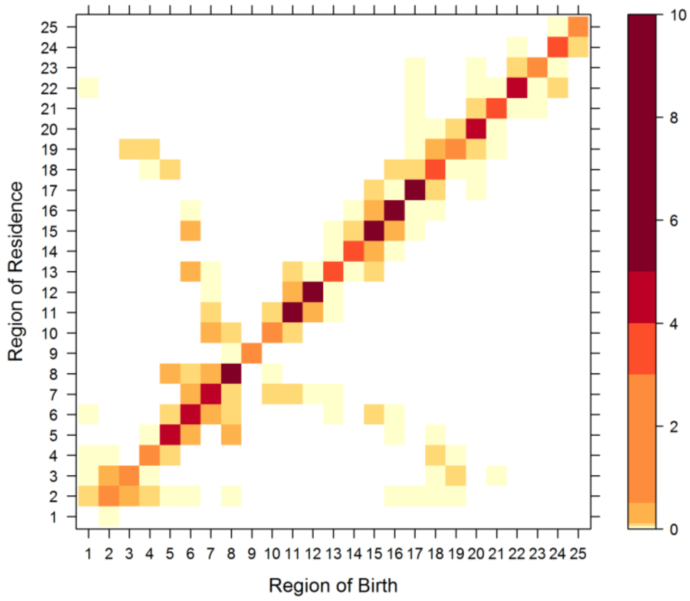
Appendix 1: Migration matrices of women in childbearing age by social status

The graphs show for each social class the share of women with a specific region of birth and region of residence combination in percentage of the Swedish total number of women of that class. The city of Stockholm is region 1, the second biggest city Gothenburg part of region 14 and the third-biggest city Malmö part of region 12.

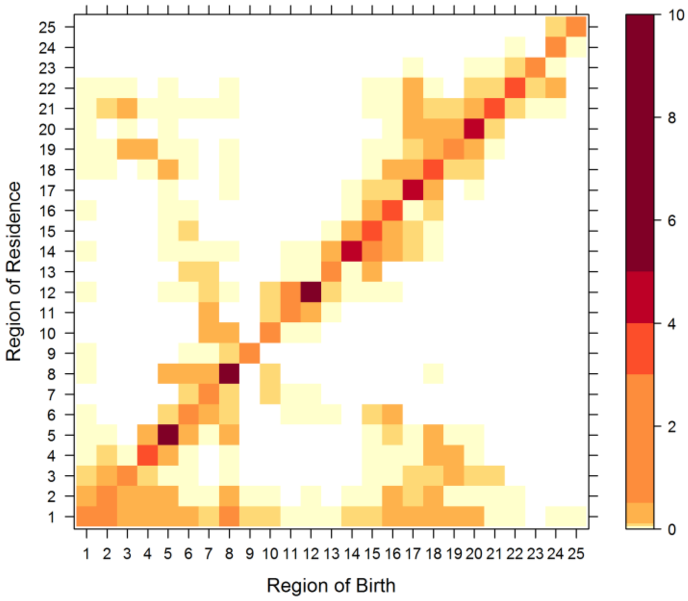
a) Elite



b) Farmer



c) Worker



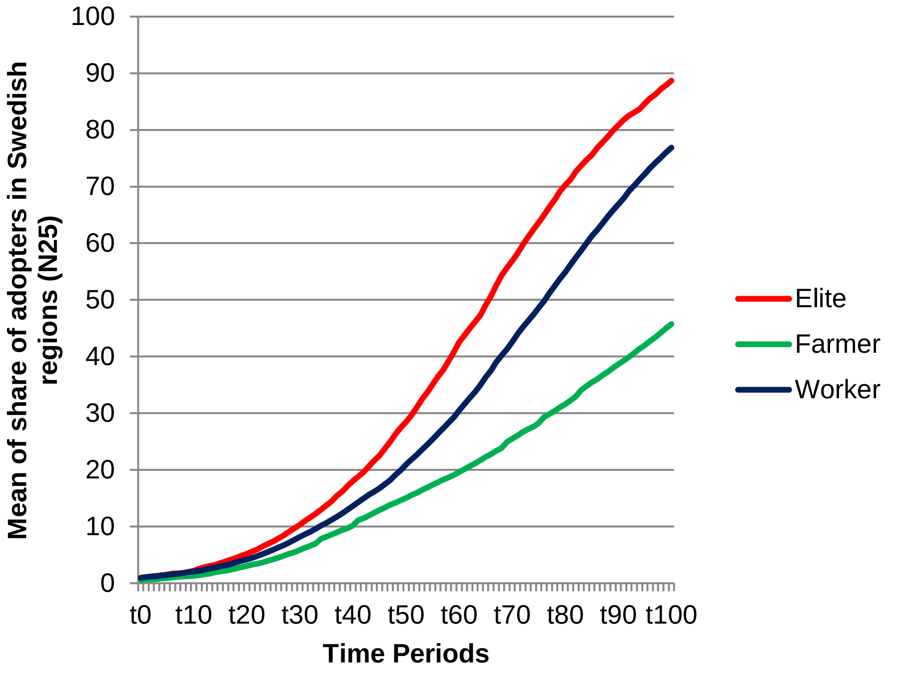
Source: Micro-level census data, SweCens, The Swedish National Archives

Appendix 2 Results of Scenario Diffusion from Big Cities

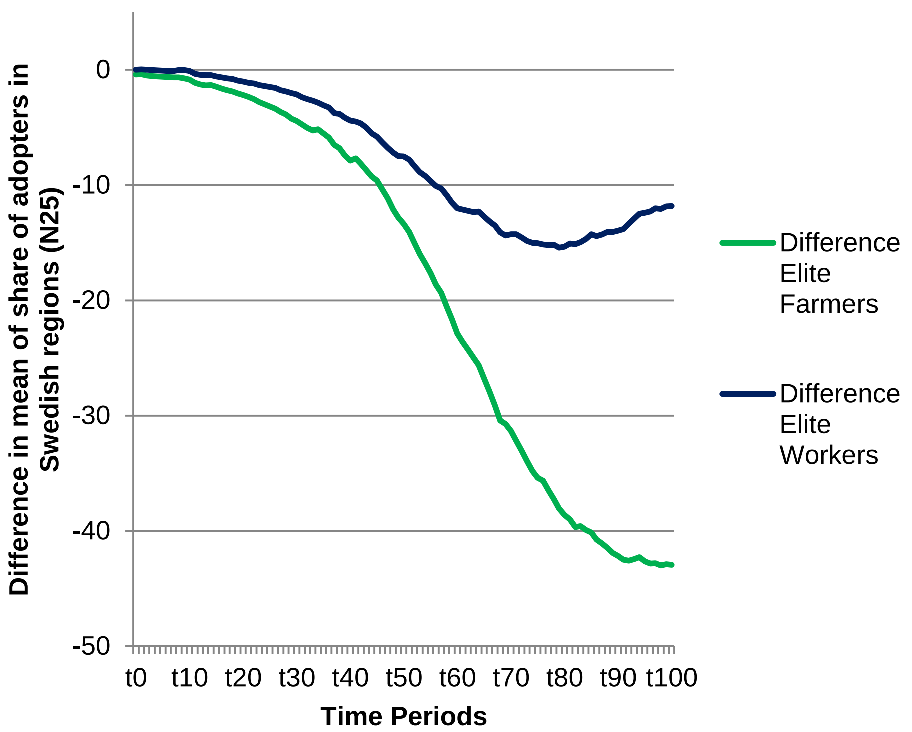
Communication Rule: Social Adaptation

Risk of Adaptation dependent on share of adaptors in region of birth (50%) and region of residence (50%)

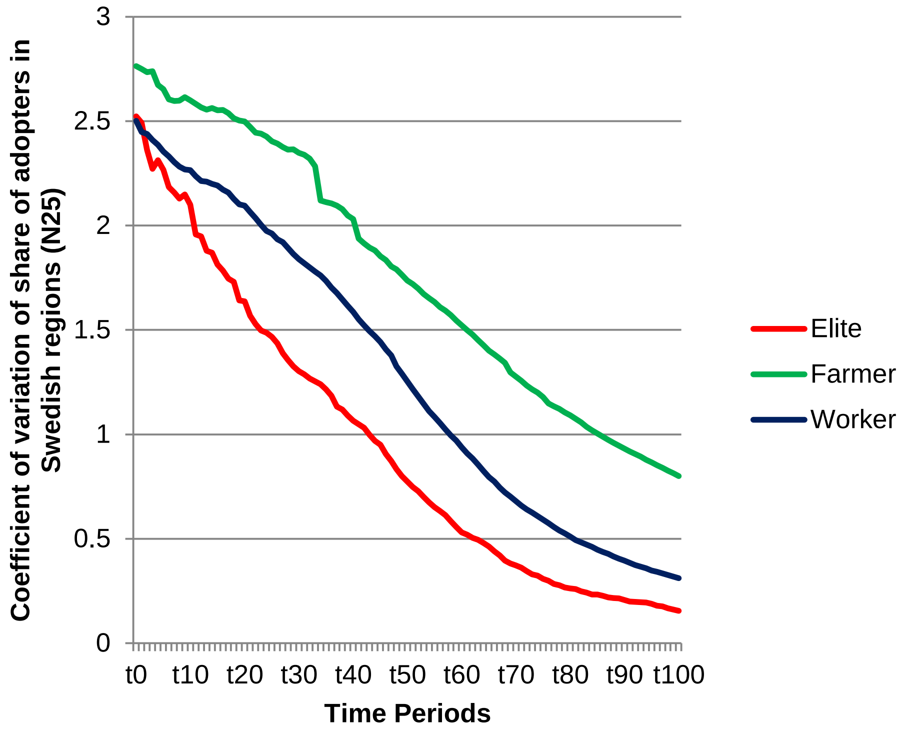
a) Development of share of adopters by social class (mean values of the 25 regions)



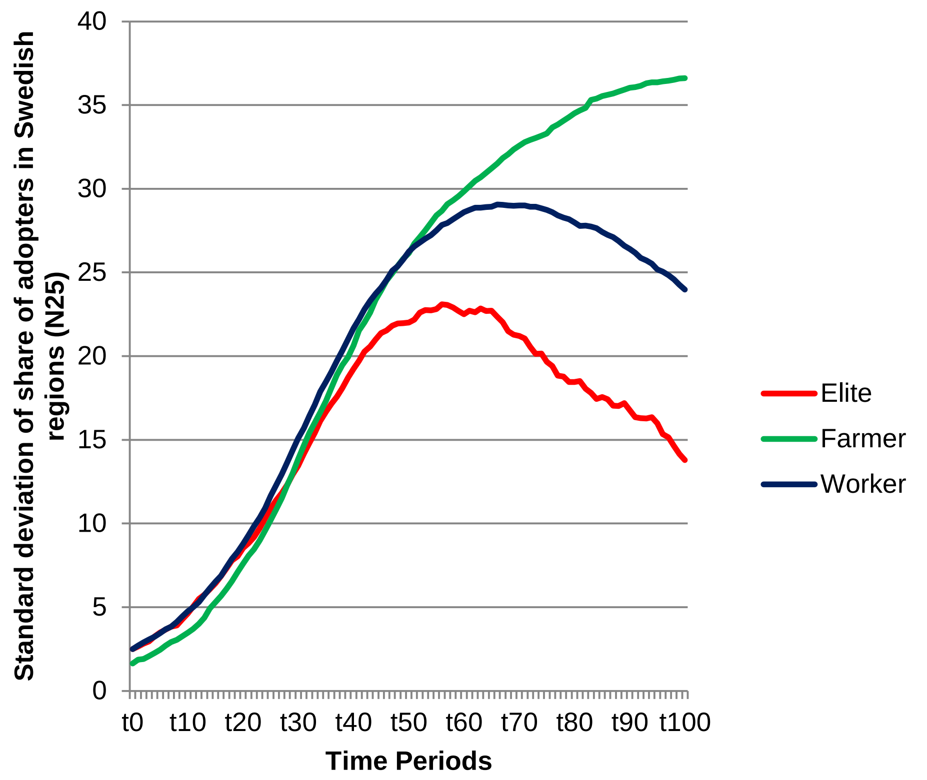
b) Social class difference in the share of adopters (based on mean values of the 25 regions)



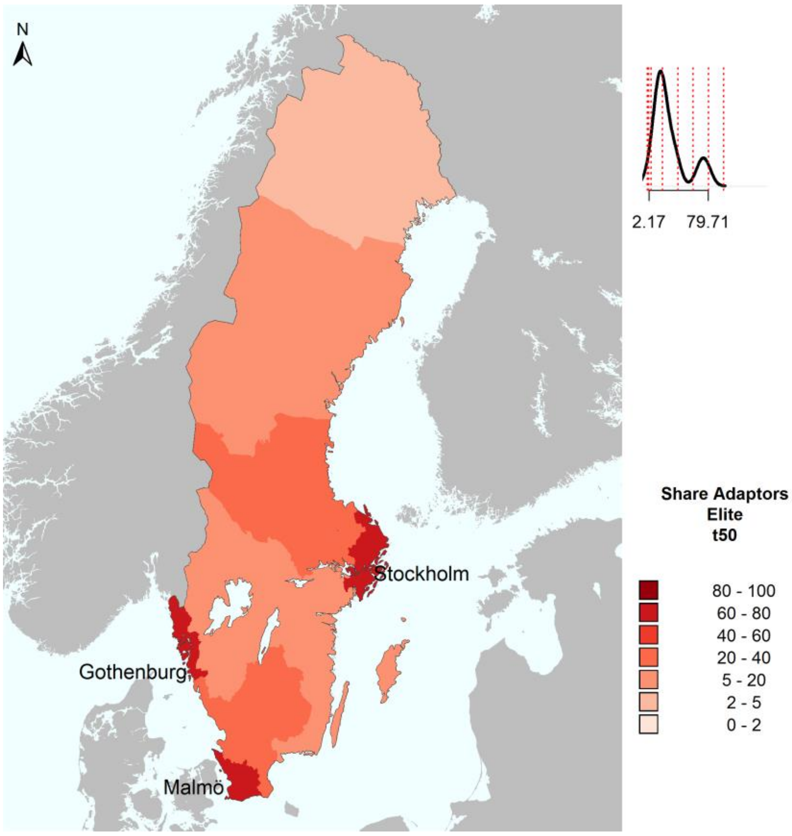
c) Variation across 25 regions by social class (coefficient of variation)

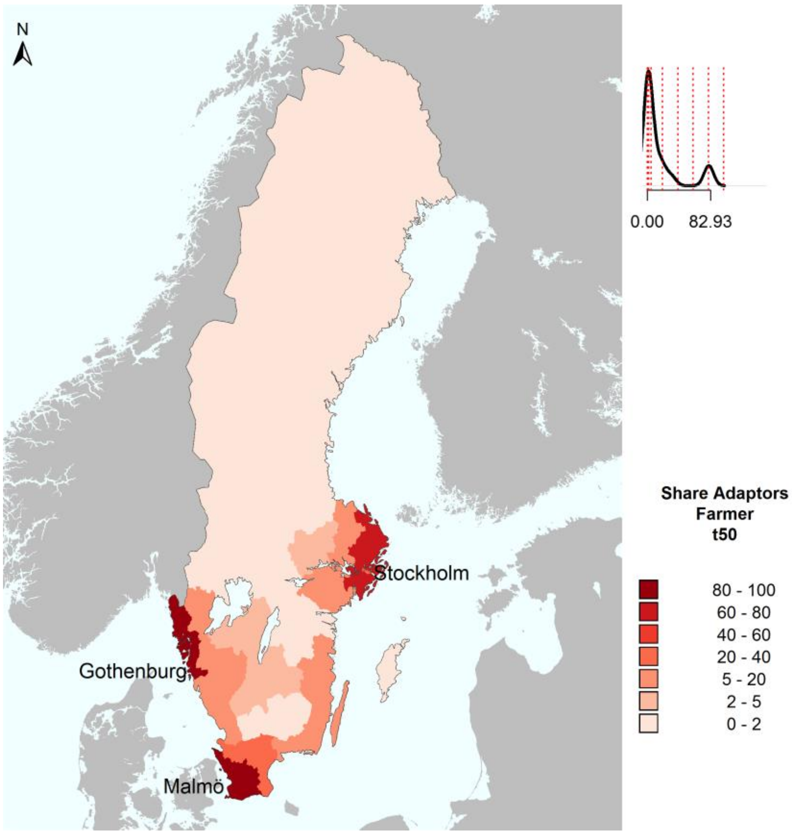


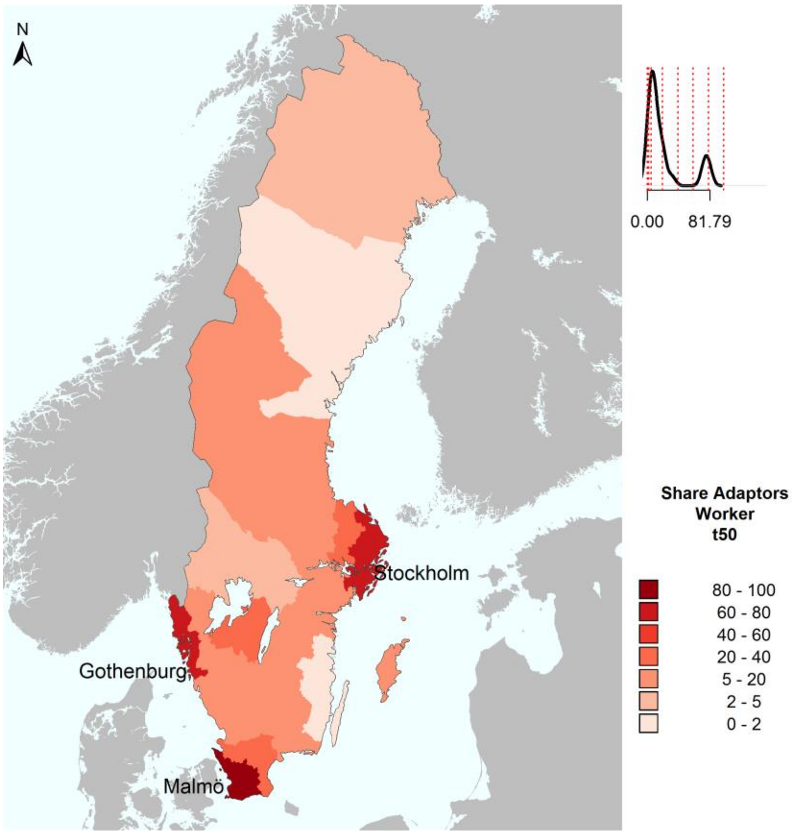
d) Variation across 25 regions by social class (standard deviation)



e) Spatial pattern by social class after 50 time periods






N
Stockholm
Gothenburg
Malmö
0.00
81.79
Share Adaptors
Worker
t50
80 - 100
60 - 80
40 - 60
20 - 40
5 - 20
2 - 5
0 - 2