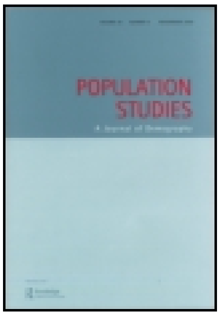

Population Studies: A Journal of Demography
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/rpst20

The effects of social interactions on fertility decline in nineteenth-century France: An agent-based simulation experiment

Sandra González-Bailón [a] & Tommy E. Murphy [b]

[a] University of Oxford

[b] Bocconi University

Version of record first published: 26 Mar 2013.

To cite this article: Sandra González-Bailón & Tommy E. Murphy (2013): The effects of social interactions on fertility decline in nineteenth-century France: An agent-based simulation experiment, Population Studies: A Journal of Demography, DOI:10.1080/00324728.2013.774435

To link to this article: http://dx.doi.org/10.1080/00324728.2013.774435

Population Studies, 2013
http://dx.doi.org/10.1080/00324728.2013.774435

Routledge
Taylor & Francis Group

The effects of social interactions on fertility decline in nineteenth-century France: An agent-based simulation experiment

Sandra González-Bailón[1] and Tommy E. Murphy[2]
[1]University of Oxford; [2] Bocconi University

We built an agent-based simulation, incorporating geographic and demographic data from nineteenth-century France, to study the role of social interactions in fertility decisions. The simulation made experimentation possible in a context where other empirical strategies were precluded by a lack of data. We evaluated how different decision rules, with and without interdependent decision-making, caused variations in population growth and fertility levels. The analyses show that incorporating social influence into the model allows empirically observed behaviour to be mimicked, especially at a national level. These findings shed light on individual-level mechanisms through which the French demographic transition may have developed.

An Appendix (González-Bailón and Murphy 2013) to this paper is available at: http://dx.doi.org/10.1080/00324728.2013.774435

Keywords: fertility decline; demographic transition; diffusion; France; simulation experiments; agent-based models; decision-making; social norms; social interactions

[Submitted January 2011; Final version accepted May 2012]

Introduction

Fertility transitions have generated both great interest and considerable controversy among social scientists. Many regions of the world have experienced systematic falls in their birth rates, representing a major demographic break with the past, and forming, it may be argued, a crucial intermediate step on the path to modern economic growth for these regions (Galor 2005). Economic, social, and cultural factors have all been proposed as potential drivers of the falling birth rates (van de Kaa 1996; Friedlander et al. 1999; Guinnane 2011), but no single dominant explanation has emerged, and there is persistent disagreement about the forces underlying the various fertility transitions observed (Mason 1997). This paper suggests a way to integrate the many components thought to contribute to fertility decline into a single exploratory framework. We present an agent-based simulation that combines a behavioural model of fertility choice with the fragmentary historical information available for nineteenth-century France, which we have used to compare the relative success with which different decision rules reproduce the aggregate patterns of fertility and population growth observed during the French demographic transition.

While still under-explored, agent-based simulation has been identified as a promising method for use in demography (Burch 1996; Billari and Prskawetz 2003; Hobcraft 2006). We used it to build an experimental setting in which to test various fertility scenarios and to measure the effect of these on population dynamics. The procedure is a novel way to study demographic dynamics, one that allows the interpretation of sparse empirical data within a formal theoretical structure.

We incorporated data from nineteenth-century France into the simulation model and used this to reproduce the known demographic landscape of the country at that time. We then went on to explore how sensitive aggregated patterns were to different behavioural assumptions within the model. This strategy allowed us to include in the model two components which have normally been neglected in the more quantitative literature on historical fertility decline: the role of social interaction in shaping fertility decisions (Kohler 2000a, b) and the connection between major social transformations and individual behaviour.

There are two reasons why the French fertility decline offers an excellent case study through which to study the effects of social interaction in demographic behaviour. First, as described below, the French decline followed a very characteristic pattern of spatial diffusion that is highly suggestive of a process of social influence. Second, the beginning of the decline, in the last decade of the eighteenth century, coincided with the French Revolution, which, it is argued, shook long-held views on fertility control by shifting norms and expectations of behaviour. Thus our study is linked with a recent line of research that views the French Revolution as a 'natural' experiment (Acemoglu et al. 2009; Acemoglu et al. 2010), and also to a growing body of research which posits a close connection between social upheaval and fertility decline (Lesthaeghe and Wilson 1986; Binion 2001; Caldwell 2004; Bailey 2009). We tested the specific hypothesis that the dismantlement of the Catholic Church in France, by those holding power after the events of the summer of 1789, contributed to the reduction in France's fertility rate (Sutherland 2003, p. 345). Through our simulation we modelled some of the mechanisms thought to be involved in this process and evaluated whether their effects on the dynamics of the French demographic system were consistent with observed empirical data. None of the hypothesized mechanisms can be tested directly because there are no historical records with the detail required to identify decision-making mechanisms at the individual level. For this reason, our study had to be exploratory rather than explanatory. Nevertheless, we were able to explore the link between the motivations of individuals and aggregated patterns of demographic behaviour in a systematic way.

Our study responded to several of the points raised by John Hobcraft in his plea to revise the way in which research on demographic behaviour is conducted (2006, pp. 155–73). First, we brought together concepts from different disciplines, such as the family decision-making process—standard within economics —and the analysis of social interaction pursued by sociologists. Second, we considered how these factors—especially social learning and social interaction— shaped fertility-related behaviour. Finally, we acknowledged the importance of context and included it explicitly in our models. In doing so, we attempted to connect with the literature which focuses on *how*, rather than *why*, fertility decline took place.

The model we present combines historical demographic data, such as mortality rates, with spatial information, including the location of major cities. Within the artificial society of the model, thousands of agents are born, live, and die, following a series of behavioural rules. These rules, which form the core of the study, represent the effects on fertility decisions of different factors, especially child mortality and social influence. We evaluated how changes in the specification of these rules resulted in variations in the long-term demographic trends estimated by the models.

Since there was limited evidence to discriminate between alternative decision-making mechanisms, the simulations were not capable of providing causal explanations of fertility behaviour, but they did help to identify theoretical dimensions of the fertility transition that require further study. For example, our findings support the hypothesis that couples were not maximizing their family size during the pre-transitional period. By having fewer children than was theoretically possible, couples may have been aiming to maximize the number of their *surviving* children, thus emphasizing the role child mortality could play in fertility decisions. We also show, using a simple interpretation of how the French Revolution affected religious practice and beliefs which, in turn, affected fertility-related behaviour, that it is possible to replicate some stylized facts concerning the country's fertility transition. This offers support to the argument that the dismantling of the Catholic Church during the revolutionary period played a role in triggering fertility decline in France.

Fertility choices and social interaction

The influence of social interaction on reproductive behaviour has lately gained considerable attention from demographers (e.g., Casterline 2001). However, hypotheses linking social interaction with fertility can be traced back to at least the late nineteenth century, when some authors attributed the fall in French birth rates to changes either in the nature of social dynamics (Dumont 1890, p. 130) or in the moral order of society (Leroy-Beaulieu 1896, p. 614). These ideas gained support in the 1970s with the publication of the first results of the European Fertility Project. In the main account of the project, Coale and Watkins (1986) summarized its principal results, which turned out to be contrary to the predictions of the then dominant demographic transition theory. Across Europe, levels of child mortality, urbanization, and industrialization did help to explain some local differences in the dimensions of fertility decline but, from a broader perspective, countries at different stages of development had experienced almost simultaneous fertility transitions. Fertility patterns were also shown to be strongly correlated with the distribution of various cultural traits, such as language. This evidence suggested that the diffusion of new reproductive behaviour was driven by social interactions (Knodel and van de Walle 1979, p. 239), and that it was the spread of new ideas, not the change in material conditions, which accounted for the decline in the number of children born to couples (Cleland and Wilson 1987, p. 27).

The degree to which social interactions, such as peer effects or social diffusion, may explain changes in fertility behaviour has been the subject of some controversy. Economists, in particular, view accounts of the fertility decline involving diffusion with scepticism because they appear to be at odds with the concept of couples acting as rational agents. They argue that, given the availability of such contraceptive means as *coitus interruptus* (van de Walle and Muhsam 1995), high fertility in the pre-transition period must have reflected a high demand for children, not an unwillingness to control fertility on moral grounds (e.g., Brown and Guinnane 2002, p. 40). Of course, social constructs such as moral norms are not necessarily outside the calculations of rational agents (Iannaccone 1992, 1998), as recent fertility-choice models have demonstrated (Kohler 2001).

The implementation of appropriate fertility models still faces a series of challenges. In particular, models that include social effects require theory and application to be tightly integrated (Durlauf and Walker 2001, p. 131), something that is not always easy to attain. In this paper, we suggest that using agent-based modelling to consider a variety of possible scenarios provides a favourable environment in which to achieve that integration. While anchored in empirical data, the models can be based on formal theory incorporating elements drawn from work on both micro-economics and social influence.

An all-embracing theoretical context

Recent research on fertility has proposed various models in which social interaction is assumed to affect rational, utility maximizing couples (e.g., Durlauf and Walker 2001; Kohler 2001). According to these models, fertility choices are seen as 'co-ordination' problems: for each couple the benefits of choosing low or high fertility are dependent on the fertility choices of others. Agents face a value function, V, that has the following general shape:

$$V(n(f_i), Z_i, F_i^e, \varepsilon_i(f_i)) = u(n(f_i), Z_i; \beta) - \frac{J}{2}(f_i - F_i^e)^2 + \varepsilon_i(f_i). \qquad (1)$$

Each agent i is characterized by a vector Z_i of personal attributes (including tastes, environmental factors, etc.) and chooses a fertility strategy f_i (typically either to use contraception, f_c, or not, f_{nc}) which takes into consideration her expectations, F_i^e, of what others are doing in terms of fertility. The terms β and J are parameters defining the general shape of the utility function, u, and the importance given to other people's fertility behaviour, respectively. The right-hand side of the equation is then divided into three parts: the personal utility that agents obtain from choosing a particular strategy which produces $n(f_i)$ children ($u(n(f_i),Z_i;\beta)$); the cost faced if they deviate from the average behaviour of the other agents $\left((J/2)(f_i - F_i^e)^2\right)$; and an external personal shock $\varepsilon_i(f_i)$.

The first term conveys much of what is now the standard economist's approach to fertility (van de Kaa 1996, pp. 409–14): a change in environmental conditions, such as an increase in wages, directly affects the personal utility leading a woman and her spouse to adjust their fertility strategy. However, the literature is divided on whether the assumption that couples cared about completed family size is valid for pre-transitional societies (e.g., Carlsson 1966; Cleland and Wilson 1987). An equally contested issue in the literature is the role of infant or child mortality in fertility decision-making. There are a number of reasons why the loss of a child, or children, could affect fertility (van de Kaa 1996, pp. 405–9), the most obvious being that families did not care about fertility per se but wished to have $n(f_i)$ *surviving* children and would therefore seek to replace a child they had lost. Empirical evidence on the connection between mortality and fertility is mixed. The findings of the Princeton project provided little support for the existence of such a relationship (e.g., van de Walle 1986) but recent research has suggested that parents were indeed taking child mortality into account before the fertility transition (e.g., Reher 1999, Reher and Sanz-Gimeno 2007). Our simulations explore this issue further.

Equation (1) can be used to illustrate the impact of religion, one type of non-market influence, on fertility choices. The role of religion is a recurrent theme in the literature (e.g., Derosas and van Poppel 2006), but one that is rarely examined in a formal way. Religion affects the utility of agents directly, through a subcomponent of Z_i which assigns a positive or negative impact to a particular fertility-strategy choice. If belonging to a religious group imposes norms of fertility behaviour that contrast with the strategy agents wish to pursue, they will face a cost (Iannaccone 1992). If $x(f_i)$ is the 'reward' an agent receives from her religious institution for choosing a particular strategy, and a simplifying assumption is made that there is no interaction between this reward and other aspects of the utility function, equation (1) may be written as

$$V(n(f_i), Z_i, x(f_i), F_i^e, \varepsilon_i(f_i)) = u(n(f_i), Z_i; \beta') + x(f_i) - \frac{J}{2}(f_i - F_i^e)^2 + \varepsilon_i(f_i). \quad (2)$$

For a religious person $\partial u/\partial x > 0$ and for a non-religious person $\partial u/\partial x = 0$; that is, the religious agent will care about the reward the religious institution can provide. If the religious institution condemns contraception in any way, the reward for an individual who does not use contraception will be greater than for one who does, $x(f_c) \leq 0 < x(f_{nc})$, and those controlling fertility will be faced with a disutility.

The term $(f_i - F_i^e)^2$ in equations (1) and (2) deals with other aspects of social interaction. There are various reasons for its inclusion, the most straightforward being that it is a way of representing social pressure. Another is the uncertainty faced by individuals. Over the course of an agent's life, the important decision on whether or not to reproduce is taken relatively infrequently. Thus people have to rely on the experience and judgment of others in order to make an assessment of their own best course, which introduces a specific form of social interaction—that of learning. Including this component in the value function can result in very particular birth-rate dynamics, which explain a series of empirical puzzles associated with the presence of multiple equilibria, high fertility 'traps', and the timing of some transitions (e.g., Kohler 2000b, 2001).

If we take equation (2) to be a reasonable approximation of the way an agent chooses her family size, it is easy to see why economic modernization does not *necessarily* result in an immediate fall in the birth rate. Any improvement in utility stemming from the reaction to different economic conditions—conveyed by Z_i—must first offset both religious *and* other social costs. Once this threshold is passed, an endogenous mechanism is triggered. The expectations of each agent concerning the behaviour of other agents (F_i^e) begin to change and this leads, via self-reinforcing dynamics, towards a new, generalized fertility strategy within the population. At the same time, non-economic modernization such as a relaxation of religious norms (represented by a decrease in $x(f_i)$) or a weakening of social ties (a fall in J) can render the value function more sensitive to even small changes in the basic components.

The complex nature of this type of model challenges empirical analysis, especially when it comes to their econometric implementation (Durlauf and Walker 2001, pp. 131–3). In order to address these challenges, we made the agents in our simulation model follow different versions of a behavioural rule inspired by equation (2), and assessed how the changes affected the aggregate demographic outcomes. To facilitate empirical calibration, we ensured that the model reproduced the geography and demographic history of France in the eighteenth and nineteenth centuries in an attempt to replicate previously observed patterns of fertility decline.

Modelling French demographic history

The decline in fertility rates occurred earlier in France than in any other European country (see Figure 1) and does not seem to have been triggered by any major economic change. The onset of the decline coincided with the French Revolution, but the actual mechanisms by which these two events were connected are far from clear (Weir 1983; Wrigley 1985a, b). Within France, fertility rates followed interesting patterns. Systematic information covering the whole country is available at the *département* level from the early nineteenth century (van de Walle 1974; Coale and Watkins 1986; Bonneuil 1997). Figure 2 plots, for each *département* at selected dates, the Princeton index of marital fertility, I_g, which relates the number of births observed among married women in the observed population to the maximum number biologically attainable given their age structure.

Throughout the 1831–1911 period, the maps show two distinct zones of low fertility: the valley of the Seine and the region of Aquitaine in the south-west. Over time, these two areas 'spread', reducing the areas of two 'islands' of high fertility: the region of Bretagne in the north-west and the Massif Central in the centre-south-east. As early as 1831, for example, one can find clear evidence of fertility limitation in such *départements* as Gironde, Lot-et-Garonne, and Eure, where indices were below 0.40; as late as 1911, however, places such as Finistère or Côtes-du-Nord were resisting change and still had indices above 0.70, indicating little or no limitation. The maps in Figure 2 suggest a slow process of diffusion of fertility limita-

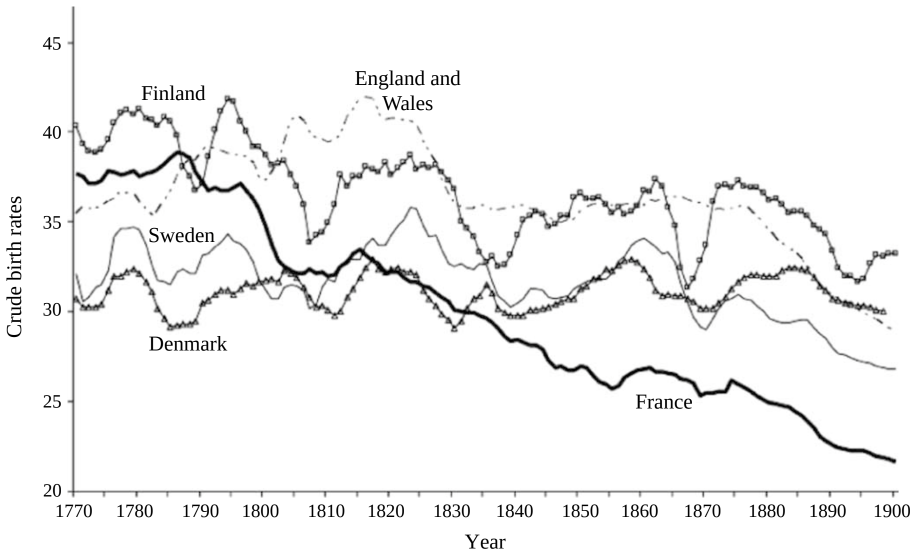

Figure 1 Crude birth rates (births per 1,000 population, 5-year averages, centred on the year indicated) for selected European countries, 1770–1900

Source: For France, see INED (1977, pp. 332–3); for England and Wales, see Wrigley and Schofield (1981, pp. 531–5); for Sweden, Denmark, and Finland, see Gille (1949, p. 63) and Chesnais (1992, pp. 518–41).

tion from the Parisian and Aquitaine basins towards these high-fertility regions, placing France in stark contrast with other regions of Europe, where such diffusion either proceeded too rapidly to be observed or was not evident at all. A comparison with England makes this contrast clear. On the other side of the English Channel, changes in fertility were relatively homogenous across the country; it is difficult to point to heterogeneity among the counties at any given time (see Figure A4 in the online Appendix). If there was a process of diffusion taking place in England, it either happened at a much faster pace than in France, or in a non-spatial dimension, which might be measured by educational level or socio-economic status (see, e.g., Szreter 1996; Bocquet-Appel and Jakobi 1998; Garrett et al. 2001).

While diffusion offers an appealing way of describing the patterns of fertility decline observed in France (Bocquet-Appel and Jakobi 1998, p. 190), it is not the only plausible way to interpret the evidence. Unfortunately, data limitations do not allow an assessment to be made of when the process of decline actually started. By 1831 there was already some degree of heterogeneity of I_g within France, but we can only speculate as to the degree of heterogeneity present in the eighteenth century. Some further information was provided by Henry and Houdaille in their analyses of the INED (Institut National d'Etudes Démographiques) sample, which was produced by a large family reconstitution project on the demography of around 40 French villages between the late seventeenth and early nineteenth centuries (Henry 1972, 1978; Henry and Houdaille 1973; Houdaille 1976). The analyses showed that there were some regional differences between 1670 and 1829, although it would appear that the variations in fertility levels they observed were largely explained by age-at-marriage patterns.

One potential explanation for the spatial evolution of French fertility rates is that the patterns were the result of a process of homogenization arising from a change affecting the whole country. One such change, suggested by Le Play (1874), was the introduction of the Napoleonic Code. If this hypothesis was correct and the Code did act as a 'trigger', over time we should see a decline in the mean fertility rate as well as declining variance in the levels of fertility seen among *départements*. Under the hypothesis of diffusion, however, the data should first show an increase in population heterogeneity followed, after a peak, by a decrease.

As Figure 3 illustrates, the mean level of fertility, I_g, falls as expected from the 1830s, until, in the second decade of the twentieth century, it stabilizes at a value of around 0.32, which was then maintained until at least the mid-twentieth century, although this is not shown in Figure 3. In contrast, the coefficient of variation across *départements*, CV(I_g), shows a clear upward trend, before falling sharply around the beginning of the twentieth century, reaching values of approximately 0.20 in the 1920s, and falling even further to 0.13 in the 1960s. The greatest heterogeneity in marital fertility across *départements* was thus found in the late, rather than the early, nineteenth century. It is possible that variation in fertility levels, rooted in the socio-economic differences

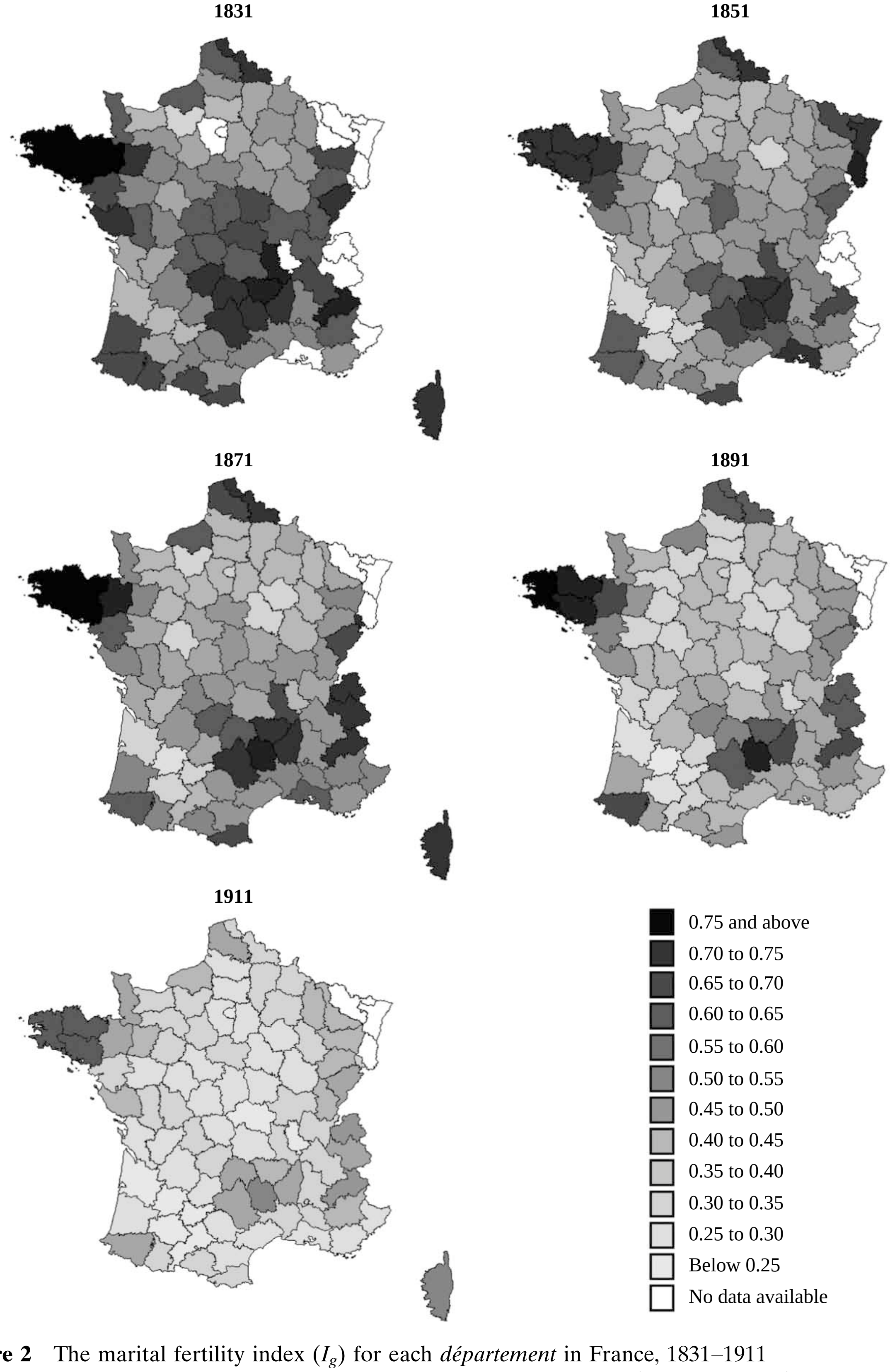

Figure 2 The marital fertility index (I_g) for each *département* in France, 1831–1911
Source: Maps constructed by the authors, using data from Coale and Watkins (1986, pp. 94–107).

found across the regions, existed in the eighteenth century, but Figure 3 suggests that even if this were the case, something else correlated with fertility was also diffusing across France over the course of the nineteenth century.

The simulation experiment

Our simulation treated the evolution of family size as the dependent variable and the demographic and geographical constraints, calibrated empirically, as

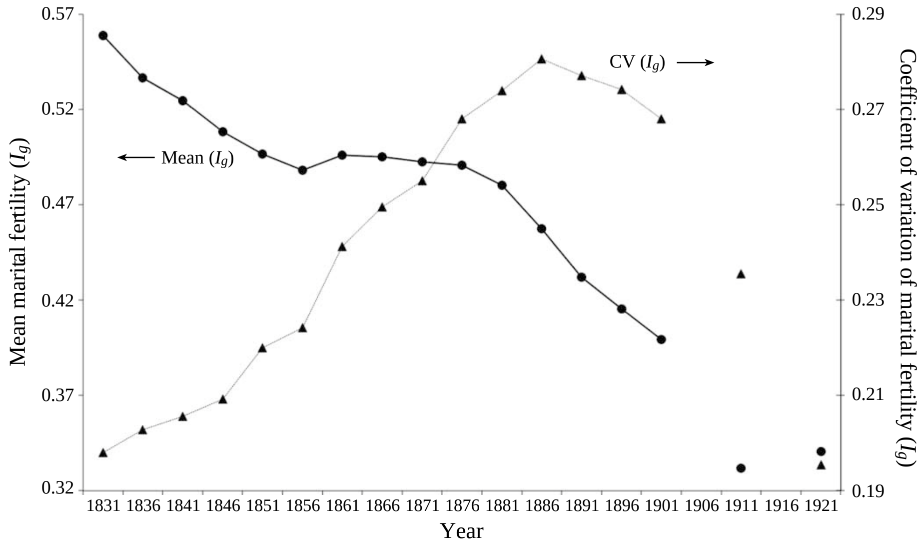

Figure 3 Mean and coefficient of variation of marital fertility (I_g) across *départments*, France, 1831–1921
Source: Constructed from data in Coale and Watkins (1986, pp. 94–107).

controls. The two main factors with which we wished to experiment were the rules which determine how agents interact with each other, captured in equation (2) by the term $(f_i - F_i^e)^2$, and the exogenous impact of the French Revolution, which was held to have prompted a change in the normative setting, which we interpreted in terms of the component $x(f_i)$. The model allowed us to evaluate the effects of switching 'on' or 'off' alternative assumptions of how individuals made their fertility choices during the pre-transitional period and within the context of the French Revolution. The aim of the simulation exercise was to compare the effects of different behavioural assumptions on the aggregate patterns of fertility rates over space and time.

A detailed description of the model appears in the online Appendix, but the main features can be summarized as follows. The simulation covers the historical period between 1740, when we first have information covering the whole of France, and 1900, when the fertility transition was well under way. It uses empirical data on at least two levels: to determine how many agents from each age group populate individual *départements*, and to define the population dynamics of each *département* using fertility and age-specific mortality rates. Within the model, agents interact in a geography that reproduces the demographic reality of France during the study period, as far as this can be determined from the available data. Fertility decisions are affected by elements of this 'known demography', such as local (*département* level) child mortality rates, but also by the knowledge agents have of their neighbours' fertility choices. As stated above, contributors to the theoretical debate on fertility decline have so far tended to emphasize the relevance of *either* material conditions or social interactions. Our simulation model incorporates *both* of these factors simultaneously in order to evaluate their relative effects on the overall population dynamics observed.

'Agents' are taken to be female members of the population because, for the sake of simplicity, distinctions by sex are not incorporated into the model. The simulation rule which guides agents' behaviour takes into account not only their own willingness to reproduce, weighted by local mortality conditions, but also the number of offspring desired by their neighbours. When agent i reaches reproductive age (taken to be 20–24 years; see online Appendix) at time t, she is held to establish her desired number of offspring ($y_{i,t}$) by considering her own inclination to reproduce (z_i), the likelihood that any child born will survive (represented by the level of child mortality, d), and the average number of offspring desired in the previous time period, $t-1$, by other fertile agents around her:

$$y_{i,t} = \alpha z_i(1+d) + (1-\alpha)\frac{1}{m}\sum_{j=1}^{m} y_{j,t-1}. \qquad (3)$$

By including d in this initial behavioural rule we explicitly assume that agents care about *completed* family size, which is, as pointed out above, a contested issue in the literature. We consider this in more detail later, comparing the outcomes of this rule with those of one where it is assumed that families aim to achieve a given level of fertility rather than a set number of surviving children.

The degree of social isolation experienced by each agent is captured by α in equation (3). This parameter determines, in a similar way to J in equation (2), the relative weight agents give to their own preferences rather than the behaviour of those around them. The larger the value of α, the more an agent is influenced by her own inclinations and less by those of her neighbours. Because individuals are most likely to look at the generation closest to them, the behavioural rule makes agents take as reference the behaviour of all other agents in the vicinity who were fertile in the previous 5-year period. In our model the term 'vicinity' or 'neighbourhood' takes a very specific meaning. Geographical proximity is defined in terms of a grid underlying the simulated map of France. Each cell in the grid measures 10 kilometres by 10 kilometres, and, as illustrated in Figure 4, the 'neighbourhood' inhabited by an agent is defined by the cell in which she lives and the eight cells immediately surrounding it, an area which would take roughly 3–4 hours to walk across.

We derived two main assumptions for our model from the theoretical approaches summarized in the previous section. First, we assume that the majority of agents in the economy are relatively close to, but not yet at, the threshold separating the old fertility order from the new. Under these conditions *non-religious agents* in *isolation* (i.e., where $x(f_i) = (J/2)(f_i - F_i^e)^2 = 0$) would adjust their fertility to a new, lower level. For a modernizing society, where many factors are encouraging individuals to have smaller families (e.g., Galor and Weil 1999), this is probably not a costly simplification. Second, we assume that, in France, agents have two alternative strategies, which are either to follow the average fertility behaviour conventional in the *ancien régime* (*ar*) or to modernize (*mo*). They make their choice by picking a fertility level from two alternative random distributions: either $Z^{ar} \sim \log N(\mu^{ar},\sigma)$ or $Z^{mo} \sim \log N(\mu^{mo},\sigma)$, where $\mu^{ar} > \mu^{mo}$ and σ is the standard deviation of the distribution, that is, a parameter defining its spread. The agents make their choices according to the behavioural rule defined in equation (3) as material conditions, such as child mortality, change. These distributions reflect the heterogeneity inherent among individuals affected by different vectors, Z_i, or some occasional shock, $\varepsilon_i(f_i)$.

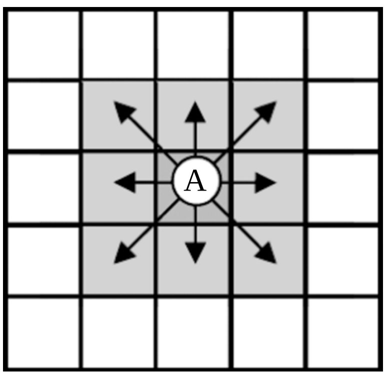

Figure 4 Grid indicating the definition of an agent's neighbours

At the beginning of each simulation exercise all agents are held to draw their inclination to reproduce, z_i, from Z^{ar}, the pre-transitional distribution. After the exogenous impact of the French Revolution, the simulation allows a number of agents to draw their z_i from Z^{mo}, a more modern distribution, thus capturing a shift in values and normative expectations. In terms of equation (2) this can be interpreted as a reduction in the reward $x(f_i)$, for following a no-contraception strategy. The 'shock' to the system takes place only once, randomly affecting agents of all ages. Those in the younger reproductive age groups will take the new distribution into consideration when choosing their family size. The fertility of more mature agents will not be affected, because they had already made their choice before the shock was experienced, but within the model they will pass their behaviour to their offspring with a probability of 1; daughters will behave exactly as their mothers had done. In terms of the debate on cultural transmission (e.g., Bisin and Verdier 2001), this feature means that within the model population direct vertical socialization—that is, socialization by the family (Cavalli-Sforza and Feldman 1981, pp. 78–84)—is perfect.

Non-family influence is partly accounted for by the parameter α, but the behavioural rule represented by equation (3) does not allow agents to decide in isolation to change their type of behaviour from 'traditional' to 'modern'. (We do not countenance the possibility that the change might go in the opposite direction.) Instead, an additional parameter, γ, is introduced which allows agents not affected by the initial shock of the Revolution to consider behaviour in their 'neighbourhoods'. If the proportion of their neighbours already following 'modern' fertility behaviour is equal to or larger than a threshold γ, then the agents change the distribution from which they draw their desired z_i from Z^{ar} to Z^{mo}. The parameter γ allows us to test the effects of a second, post-Revolution channel of social influence.

There are two ways in which such an additional channel of cultural transmission, in the form of oblique or horizontal socialization (see Cavalli-Sforza and Feldman 1981, pp. 130–3) might be important after a 'shock' of the kind generated by the French Revolution. One possibility is that the presence of 'modern' parents in a neighbourhood would reduce the uncertainty involved in deviating from traditional behaviour by demonstrating that smaller families could be economically viable and even desirable, thus increasing the utility to be expected from following a low-fertility strategy. Another possibility, suggested by the literature on the economics of religion (Iannaccone 1998, pp. 1482–4), is that if, as a result of some 'shock', a considerable proportion of the agents in a community diverge from a religious norm, the value of following that norm (represented in the equations above by the reward, $x(f_i)$) decreases for *all* agents in the community, even those not affected by the original shock. A feedback mechanism could be further expected to amplify the effects of the original shock within the local community.

In the following two sections we present the results of using the simulation model to explore the questions discussed above. First, we investigated whether different assumptions concerning social isolation generate different population dynamics, and whether the inclusion of child mortality in the behavioural rule enabled us to reproduce the empirically derived population profile more accurately. We show that these tests shed some light on whether couples may have been aiming to achieve a particular completed family size before the transition. We next assessed whether social influence, either horizontal or vertical, affected the long-term trends in family size during the fertility transition in France.

Fertility decisions in pre-transitional France

Most of the evidence from pre-transitional Europe suggests that fertility levels were more or less stable over time (e.g., Flinn 1981), and that France does not seem distinctive in this respect (Henry 1972, 1978; Henry and Houdaille 1973; Houdaille 1976). For the French case it is also well established that signs of a downturn did not become evident until after 1790 (Weir 1983; Wrigley 1985a). Given these facts it is plausible to assume that before the transition all individuals were making their choice of fertility level from a single, stable distribution (Z^{ar}), and that only after the transition started did a greater heterogeneity in choice develop (here captured by the distribution, Z^{mo}). In this section a series of simulations are presented which relate to the pre-transitional period and aim to uncover the implicit fertility decisions taken under the *ancien regime*, given various behavioural assumptions. We identified the combinations of parameters which reproduced empirically observed patterns of population growth and fertility levels. In essence this entailed finding values of μ^{ar} that were consistent with trends in population dynamics at the aggregate level under different values of α.

We set σ equal to 0.45, which is the average value for French populations at the time as estimated from empirical age-specific fertility tables (Flinn 1981). We generated sets of simulations, starting in 1740 and running until 1790, using values of μ^{ar} which ranged from 1.0 (which is equivalent to two children per family in 'the real world') to 3.0 (equivalent to six children), increasing in increments of 0.05. We also used values of α, running from 0.2, signifying virtually complete social influence, to 1, representing total social isolation. In order to assess how the different combinations of parameters affected the evolution of population levels, we plotted the average of 100 simulations against the empirical data. A representative selection of these plots is shown in Figure 5.

Figure 5 shows that several combinations of the parameters μ^{ar} and α produce good fits to the actual trend in growth observed for the French population across the eighteenth century, with alternative degrees of social influence being consistent with different levels of μ^{ar}. Simulations in which α was smaller required couples to desire a lower number of children in order to sustain the same population levels. This is probably a consequence of a smaller proportion of agents aiming to achieve lower values within the distribution of family sizes, which—while there is an upper limit to the number of children an agent may bear in her lifetime—generates a tendency to have larger families on average. In general, for every α_i there is a μ_i^{ar} which allows us to predict population growth well, and the fit we obtain from an optimal pair of (μ_i^{ar}, α_i) values (optimal in the sense that given α_i there is no μ_j^{ar} for $i \neq j$ that produces a better fit than μ_i^{ar}) is comparable to that of any other pair as assessed by alternative goodness-of-fit measures.

A second result of interest is that, for every degree of social influence, there is a level of μ^{ar} at which the simulated population growth outstrips that seen in reality. This is not a trivial outcome; it suggests that a population with these demographic characteristics could have seen greater growth in numbers than it did. Recall that the model does not allow agents to exceed the number of children that is plausible given basic biological limitations, such as rates of fecundity and mortality and the age structure of the population, and social considerations (such as effective marriage rates). Therefore, the fact that there are values of μ^{ar} for which the simulated population

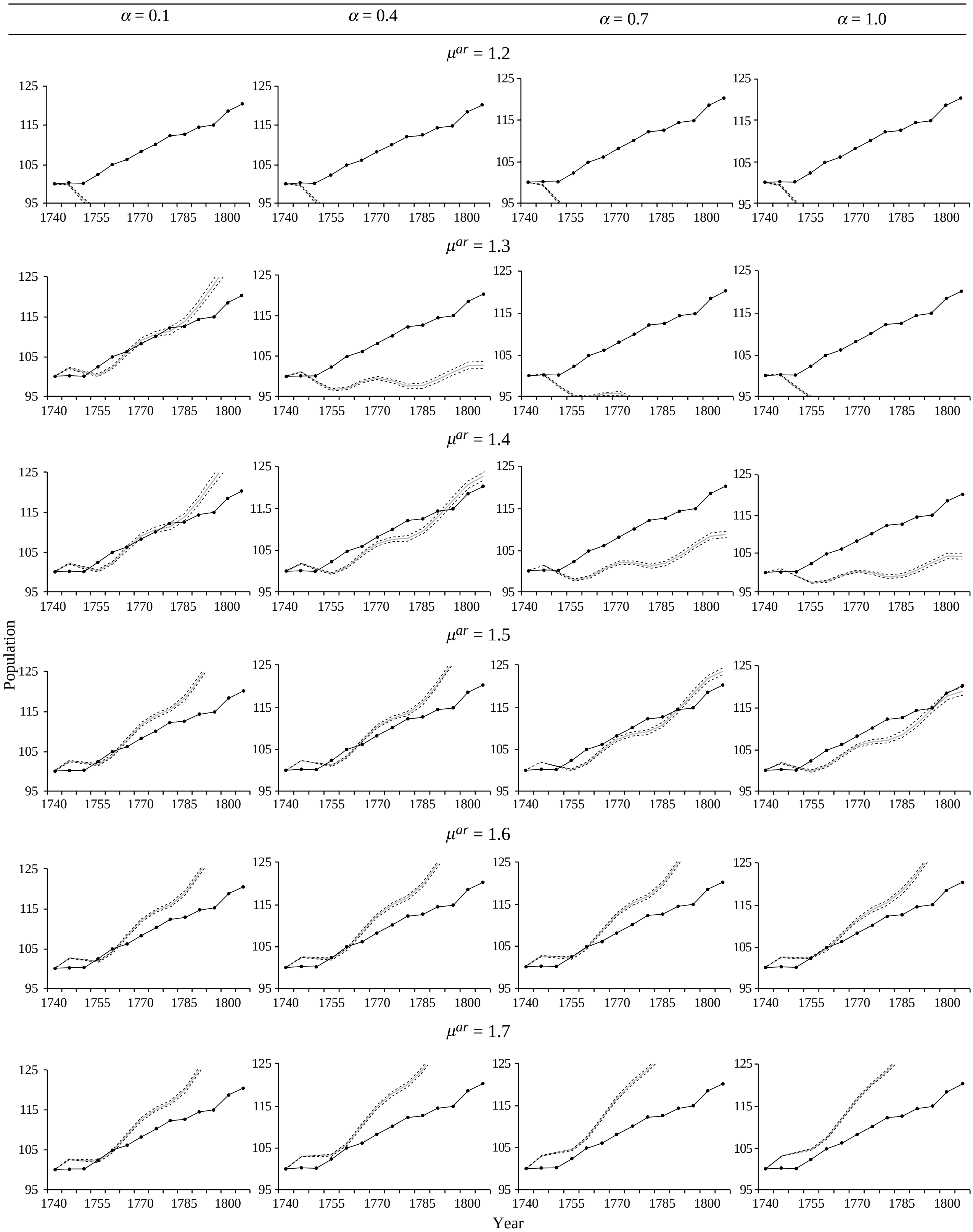

Figure 5 Actual and simulated levels of population in France (indexed against 1740 values) for different pairs of (μ^{ar},α)

Notes: Lines with symbols indicate actual values, smooth lines correspond to the average of 100 simulations, and the dashed lines 95 per cent confidence intervals. Actual and simulated populations are set equal to 100 in 1740.

Source: Actual population from INED (1977, pp. 332–3) and INSEE (1961, p. 36).

growth is considerably higher than that that actually observed in the population implies that French couples were not maximizing the number of their offspring. This may have been either because they were actively controlling births or because they were following certain social practices, such as post-partum abstinence or extensive breast-feeding, which were reducing their fertility. In effect, the graphs in Figure 5 suggest that by assuming a fertility regime in which couples achieve approximately three surviving children on average (the simulation equivalent of $\mu^{ar} \approx 1.5$), the model is able to replicate the population growth of France during the second half of the nineteenth century.

The fertility rates which the model produces are slightly lower than those observed, yet have the same stable trend. For France as a whole, our estimates of crude birth rates derived from the simulation are in the order of 30–31 per 1,000 population, whereas the empirically measured average for the second part of the eighteenth century was about 39 per 1,000 (INED 1977, pp. 332–3), a difference of approximately 30 per cent. The difference is not so large if we use other, less coarse measures, such as the Princeton indices. For the period 1740–90, for example, studies suggest average values of the overall fertility index, I_f, for the whole of France of around 0.41 (Weir 1994, pp. 330–1), whereas those derived from our model are 12 per cent smaller, at around 0.36. This difference is smaller than the discrepancies between other scholars' empirical estimates of the Princeton indices for France in the early nineteenth century (e.g., Weir 1994 vs. Bonneuil 1997).

Empirical data from before 1800 are partial and scattered, so there is no direct way to assess whether simulated fertility rates for the different *départements* across France reflect actual rates in the pre-transition period. One alternative is to compare them with the estimates for the INED sample (Weir 1983, pp. 189, 194). Since these values correspond to specific villages, one cannot really take the I_g values to be representative of the *départements* in which the villages stood, but they may provide a first, if imprecise, indicator of the simulations' performance. We find, for various (μ^{ar},α) combinations, a positive correlation of around 0.37 between Weir's estimates for the villages in the 1690–1769 period and our simulated values for the respective *départements* between 1740 and 1790, which is reassuring. We can also compare the results of the simulation with the earliest fertility figures available for each French *départment* using the I_f values calculated by Bonneuil (1997) for the period 1806–11. By the early years of the nineteenth century the fertility decline had already started in some places, yet regional differences were probably still dominated by the pre-transitional dynamics. We also find a positive, but even stronger, association between Bonneuil's figures and our results. Correlations were between 0.50 and 0.59, with pairs including high levels of α performing marginally better.

Finally, a third interesting result of this set of simulations is that when the influence of child mortality is removed from the decision rule in equation (3), the simulated fertility trends do not resemble the observed values so closely. We thus constructed a behavioural rule which *does not* take child mortality into account:

$$y_{i,t} = \alpha z_i + (1-\alpha)\frac{1}{m}\sum_{j=1}^{m} y_{j,t-1}. \qquad (3')$$

When running simulations using equation (3′), the predicted population trends are comparable to those generated by the original behavioural rule, equation (3), but the results for fertility are remarkably worse. As expected, the values of μ^{ar} that provide a good fit for the model are higher: agents must aim to achieve a mean value close to 2 (equivalent of four children in the real world) to maintain the empirically observed population growth rate. Apart from somewhat higher volatility in the series, the results at the macro level are not substantially different under this alternative behavioural rule. However, with regard to fertility, the results are markedly poorer, particularly at the regional level. There is no relationship between our estimates at the local level and those of either the INED sample or the early nineteenth-century *département* figures; correlations are significantly lower in every case, and close to zero in most of them. The results of these simulations suggest that parents were considering the number of surviving children they were likely to achieve when deciding the size of their families, and some of the observed differences in pre-transition fertility rates can thus be explained simply by differences in child mortality.

Revolution, religion, and social influence in the French fertility transition

In all versions of our simulations where pre-1790 parameters are maintained, French population growth over the nineteenth century is overestimated. This implies that at least some members of the French population must have switched their behaviour to choose from a more modern fertility distribution, as we suggested in the theoretical discussion. In this section, special attention is paid to the effects of vertical and horizontal social influence as possible causes of the fertility decline in France. We determine how well our model performs when a considerable proportion of agents in each *département* all set out to achieve an identical low number of children, and assess the degree to which the size of the proportion behaving in this way is correlated with support for the Revolution. By creating a model in which a proportion of agents all aim to achieve a common low level of fertility, as opposed to one which assumes that agents aim to achieve a variety of low levels, we address Weir's empirical observation that the fertility decline in France was the consequence of fertility control by an efficient group, and not the result of a collective choice made by all members of the population (Weir 1983, p. 104; 1984, p. 612). Also relevant is Kohler's theoretical suggestion that fertility choice can be partly understood as a coordination problem within a system with multiple equilibria (2000a).

Exogenous shocks can cause agents to reassess their expectations and coordinate their behaviour to create a new equilibrium. In the next section we explore how the French Revolution could have acted as such a shock.

Revolution and the fertility decline

Recent studies suggest that social upheavals can have profound effects on the evolution of birth rates (e.g., Caldwell 2004; Bailey 2009). That there was a connection between the Revolution of 1789 and the French fertility decline has been assumed for some time (Spengler 1938, pp. 163–74; Flandrin 1979, p. 238). The timing of the Revolution suggests it as a good candidate to explain the decline, since the first signs of a reduction in the French birth rate appear soon after 1790 (Weir 1983, p. 39). At least two lines of theoretical argument further support the hypothesis that the Revolution prompted the decline. The first of these links the ideological shift associated with the rise of a more egalitarian and democratic society (Dumont 1890; Leroy-Beaulieu 1913) with the realization amongst individuals that they could actively take decisions about aspects of their lives which historically they had taken as given (Binion 2001). The second line of argument stresses the importance of the institutional aspects of the new order—such as the modifications to inheritance laws (Le Play 1874) or the revolutionaries' promotion of agricultural capitalism (Weir 1983, p. 280)—to the generation of new modes of behaviour. There are reasons to believe that the disintegration of the Catholic Church, which was actively pursued by the Revolutionary authorities, played a key role in these changes (Murphy 2010).

There is extensive evidence suggesting a connection between religion and fertility behaviour (e.g., Derosas and van Poppel 2006). Until the early nineteenth century, Catholicism, with its strong negative attitude to contraception, remained the main norm-setter in France (Flandrin 1979, pp. 194–6; Gibson 1989, pp. 185–6). According to those who favour 'ideational shift' as an explanation, the Revolution shook the Church to its very foundations, allowing 'at least some French men and women to break free from old constraints' (Gibson 1989, pp. 244–5), and reach a new ideal normative equilibrium in terms of fertility-related behaviour. In addition, the newly formed National Assembly interfered in the regular functioning of the Church in a more literal way, by suddenly curtailing its liberties and resources, and further undermining its whole apparatus by a purge of its members. Towards the end of 1790, for example, the revolutionaries forced clerics to take an oath of allegiance to the new Constitution. This split the clergy into jurors (*constitutionnel*), who took the oath, and non-jurors (*réfractaire*), who refused to do so, fuelling confrontations amongst the clergy and at different levels of society. The nature and consequences of the oath were rather complex (Tackett 1986), but some authors have ventured the idea that the relaxation of clerical discipline in regions where the clergy supported the Constitution and the influence of the Church was diminishing, can partly explain the rapid spread of birth control in these areas. Most notably, Sutherland suggests that the oath put an end to quasi-universal religious practice in France and, in particular, limited the ways in which local priests could influence birth-control practices, thus facilitating the rise of such 'anomalies' in sexual behaviour as contraceptive practices, illegitimacy, and bridal pregnancies (2003, p. 345). Given the previous extent of the influence of the Church, it is not difficult to believe that areas where the hold of religion was weakening would have been more sensitive to the institutional changes brought about by the Revolution, which could have had an impact on their fertility.

We tested this picture of events with a second set of simulations which aimed to mimic population growth after the Revolution. One way of representing Sutherland's hypothesis in our model was to define a reduction in the costs of not following the prevalent, church-mandated norms in oath-taking areas as a drop in $x(f_i)$ for some of the agents. If these agents were already ready to change their fertility strategy, which for early modern France is a reasonable assumption, then, given the new conditions, they would have decided to make their behaviour more 'modern'. The proportion of priests taking the oath of allegiance varied substantially across the country and we used this variation to model spatial differences in ideational shift. If, for example, 25 per cent of the priests took the oath in a *département*, we assumed that a quarter of our simulated agents in the same *département* would draw their personal fertility inclination (z_i) from a distribution with a mean of μ^{mo} instead of μ^{ar}. This inclination for new fertility behaviour would then be transmitted vertically from parents to offspring, or horizontally via the parameter γ, which determines how easily this behaviour spreads over time to other agents.

Simulating the fertility transition

As discussed in the previous section, more than one combination of the parameters (μ^{ar},α) was consistent with pre-transition demographic trends. We tried several different combinations as alternative starting points for a new set of simulations, obtaining similar results with all of them. Figure 6 illustrates the results corresponding to the combination $(\mu^{ar},\alpha) = (1.5,0.7)$.

Interestingly, relatively small drops from μ^{ar} to μ^{mo} are required to replicate the evolution of the

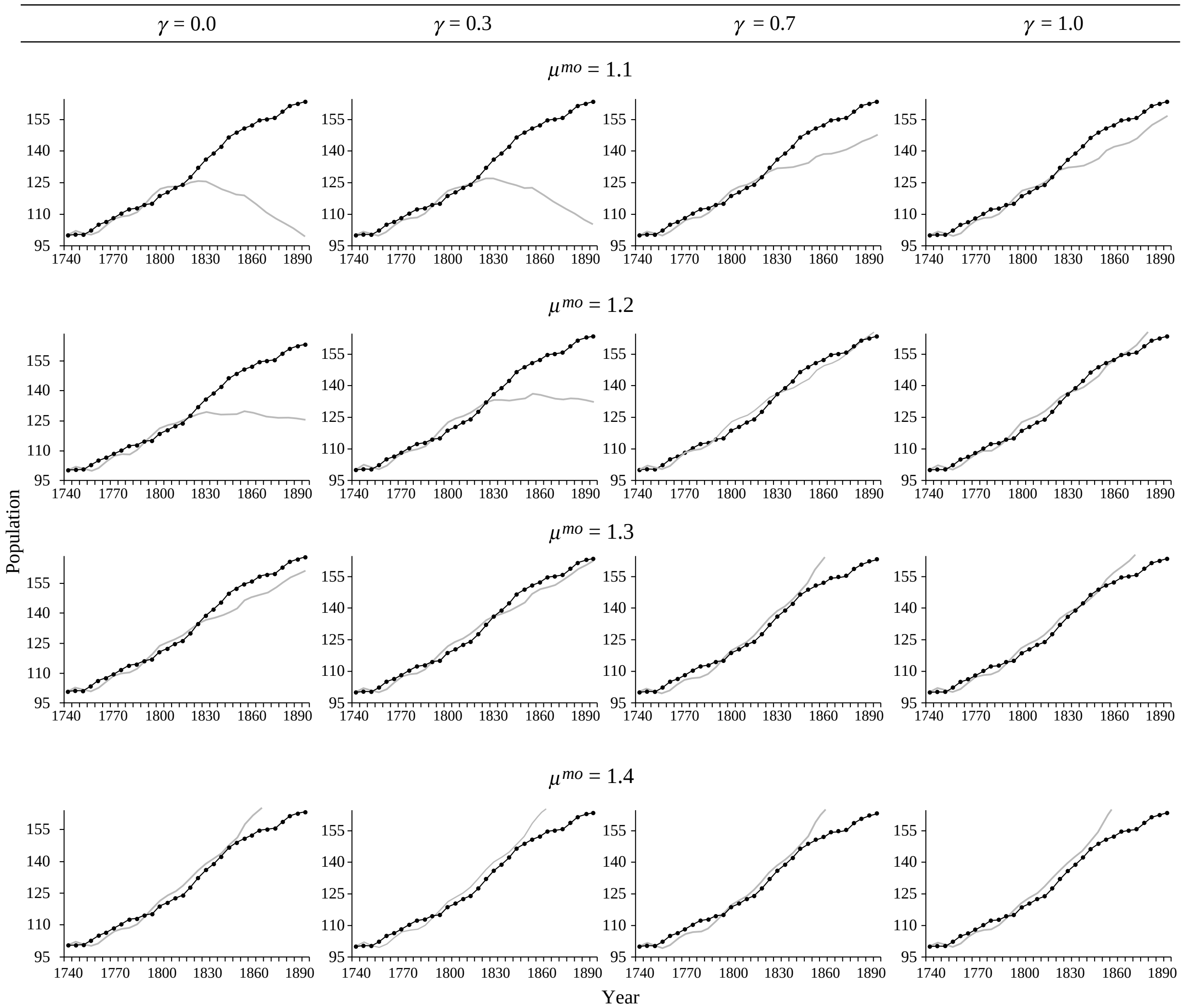

Figure 6 Actual and simulated levels of population in France (indexed against 1740 values) for different pairs of (μ^{mo},γ) when $(\mu^{ar},\alpha) = (1.5,0.7)$
Notes: As for Figure 5.
Source: As for Figure 5.

growth in population. Depending on the value of γ, with higher values denoting more restricted horizontal diffusion, a decline of less than 20 per cent in the average desired family size is enough to achieve the empirically observed rates of population growth. At the aggregate level, population dynamics are in fact quite sensitive to γ, with high values of γ requiring a larger fall in the mean of the distribution μ^{ar}. As in the previous section, we can find a series of parametric combinations $(\mu_i^{ar}, \mu_i^{mo}, \alpha_i, \gamma_i)$ which maximizes the goodness of fit of the simulated population patterns to the patterns in 'the real world' of nineteenth-century France. Figure 7 shows how different parametric values affect fertility trends: the upper panel (a) holds γ constant and varies α; the lower panel (b) holds α constant and varies γ.

The match between the simulated and observed data is far from perfect, yet it is within the range of discrepancies found between alternative empirical estimates of I_f for the period (see discussion in Bonneuil 1997, pp. 90–2). The simulated trends do change in line with the trends observed in the French population. The results with the closest fit to the observed population in both panels come from parametric combinations where social isolation effects were present but did not dominate the dynamics. In panel (a), for example, the decline is most marked when social isolation is moderate ($\alpha = 0.7$),

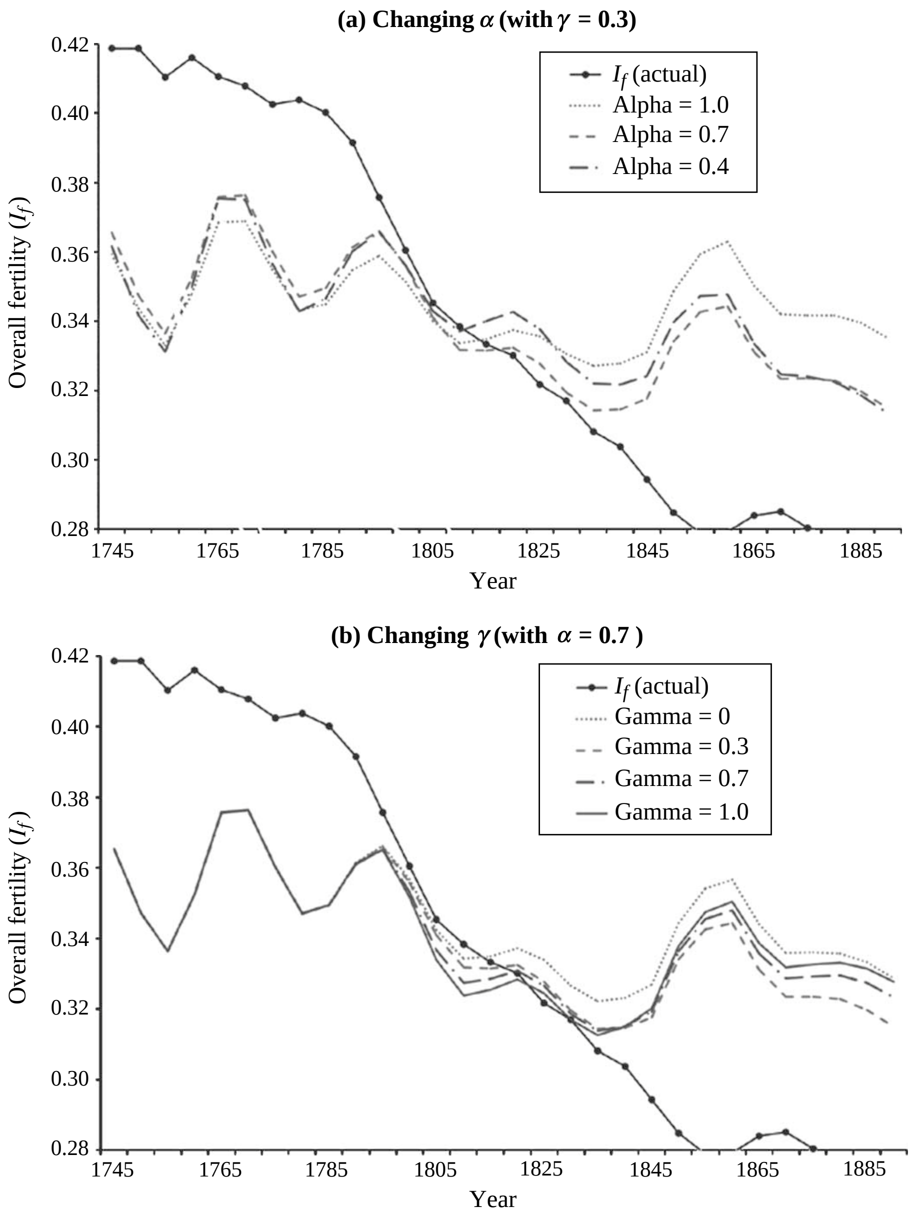

Figure 7 Actual and simulated overall fertility (I_f) when $\mu^{ar} = 1.50$, for France, 1740–1900
Notes: Lines with symbols indicate actual values and other lines correspond to average of 100 simulations.
Source: Overall fertility 1740–1900 as estimated by Weir (1994, pp. 330–1).

but much less so when it is low ($\alpha = 0.4$) or at its highest level ($\alpha = 1.0$). In panel (b) the least appropriate combination is that in which $\gamma = 0$.

For the first few decades of the transition, in the early nineteenth century, the model matches the timing and pace of the fertility decline relatively closely. It does not perform so well for the later part of the century. The most likely explanation for this is the inherent simplicity of the intervention imposed. Since only one, once-and-for-all decline in μ was allowed, this ruled out the possibility of further declines which would otherwise have been quite plausible, such as those motivated by a secular increase in wages or the expansion of schooling, or those resulting from important historical shocks such as the Franco-Prussian war. Not allowing other parameters to change might also have been important; for example, it was assumed throughout that both α and γ were constant across time, but these may well have been changing.

The type of information used to describe the environment in which the population operated may also explain the model's relatively poor performance with reference to the later nineteenth century. For example, for the sake of simplicity it was assumed that non-child mortality remained constant throughout the period, although in fact there were small, yet persistent, improvements in life expectancy. For this reason, the simulations required a greater number of births in order to maintain the pace of population growth. The additional births inflate the numerator of our I_f, while the assumption of constant mortality keeps the denominator down, increasing the predicted fertility indices towards the end of the period. This partly explains why the figures generated by our models closely match observed rates of population growth, but are a poor fit to measures of fertility. In a similar vein, since our model uses child mortality data, it is probable that it misses certain aspects of the long-term evolution of non-infant child mortality, which some authors claim is crucial to a full understanding of the dynamics of fertility decline (see, e.g., Reher 1999, p. 15).

Just as the coarseness of the child mortality measures used may have affected the results of the simulation, so the approximate nature of I_f as a measure of fertility could also have affected our interpretation of the simulation results. Panel (b) in Figure 8 demonstrates that, because the measure of marital fertility, I_g, incorporates the fact that people were marrying earlier in the second half of the nineteenth century, it is a more useful measure when tracking fertility decline in this period than is I_f, shown in panel (a). Some of the changes in nuptiality inadvertently incorporated into our model thus explain some of the discrepancies encountered. In this way simulation models of the sort described above can help to identify aspects of fertility decline that require further research.

It is interesting to look more closely at the performance of the simulation vis-à-vis the actual data available at *département* level. Figures 9 and 10, for example, show some areas which led, or lagged, the general fertility decline in France. (The performance of a representative sample of the remaining *départments* can be seen in Figure A5 in the online Appendix.) As can be seen in Figure 9, the model reproduces well the absence of any downward trend in marital fertility in Brittany and the Massif Central. Both were areas of France where large numbers of priests refused to take the oath of allegiance, and both were sluggish in terms of fertility decline. In terms of the sum of absolute deviations between mean predicted and actual

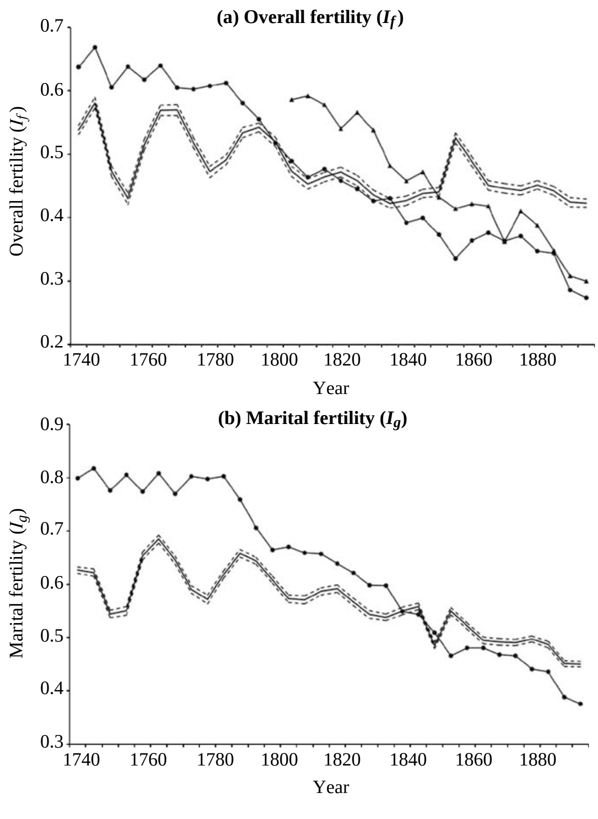

Figure 8 Actual and simulated fertility when $(\mu^{ar}, \mu^{mo}, \alpha, \gamma) = (1.50, 1.3, 0.7, 0.3)$, France, 1740–1900

Notes: Lines with symbols indicate actual values and smooth lines correspond to an average of 100 simulations (dashed lines indicate 95 per cent confidence interval).
Source: Marital and overall fertility 1740–1900 (circles) as estimated by Weir (1994, pp. 330–1), and shorter series of overall fertility 1806–1901 (triangles) as estimated by Bonneuil (1997, pp. 197–205).

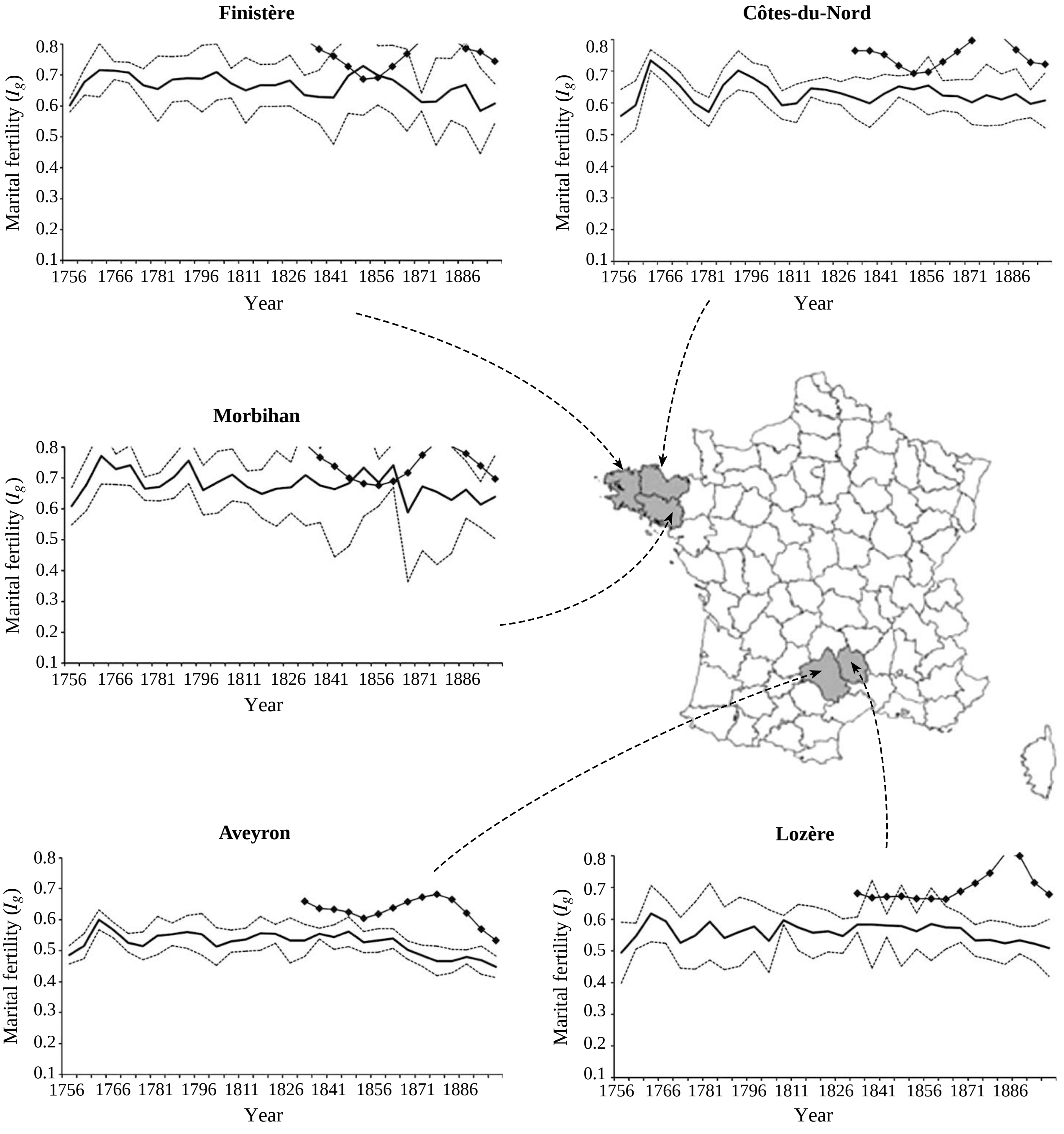

Figure 9 Actual and simulated marital fertility levels when $(\mu^{ar}, \mu^{mo}, \alpha, \gamma) = (1.50, 1.3, 0.7, 0.3)$, lagging *départements*, 1740–1900

Notes: Lines with symbols indicate actual values starting in 1831, whereas smooth lines correspond to simulation starting in 1741. Both finish in 1896.

Source: Actual values from van de Walle (1974).

fertility, the model tracks fertility better for the Massif Central than for Brittany, however. A number of factors might account for this difference. Brittany was, for example, relatively richer than the Massif Central and appears to have been largely under-taxed (Jones 1988, p. 36). This means that, *ceteris paribus*, parents had more disposable income to spend on children. If children were normal goods, families in Brittany would have been motivated *ex ante* to draw fertility from a distribution with a higher mean. Lying in the north-west of France, this region also experienced higher child mortality than the Massif Central. This led *départements* in the area to have higher levels of fertility before the transition began, which is remarkably well reflected in the results of our model. Yet if our earlier argument, that non-infant child mortality had a greater influence on fertility than infant mortality, is valid, the high level of fertility in Brittany might well have been underestimated by the model.

As Figure 10 shows, the simulations somewhat overstate the levels of fertility in the 'leading' areas, although they replicate well their generally downward trend. A few characteristics of the model could account for some of the discrepancies between the simulated results and the observed data. The model assumes homogeneity across all individuals in their vulnerability to social interaction effects—α and γ are held constant for all agents. It is certainly plausible that the propensity to follow or learn from others could vary across regions; in particular, it is likely that areas leading the decline were more 'individualistic'. It is also possible that the relationship between oath-taking by the clergy and the change in desired fertility was not linear. One may speculate that while in conservative or moderate

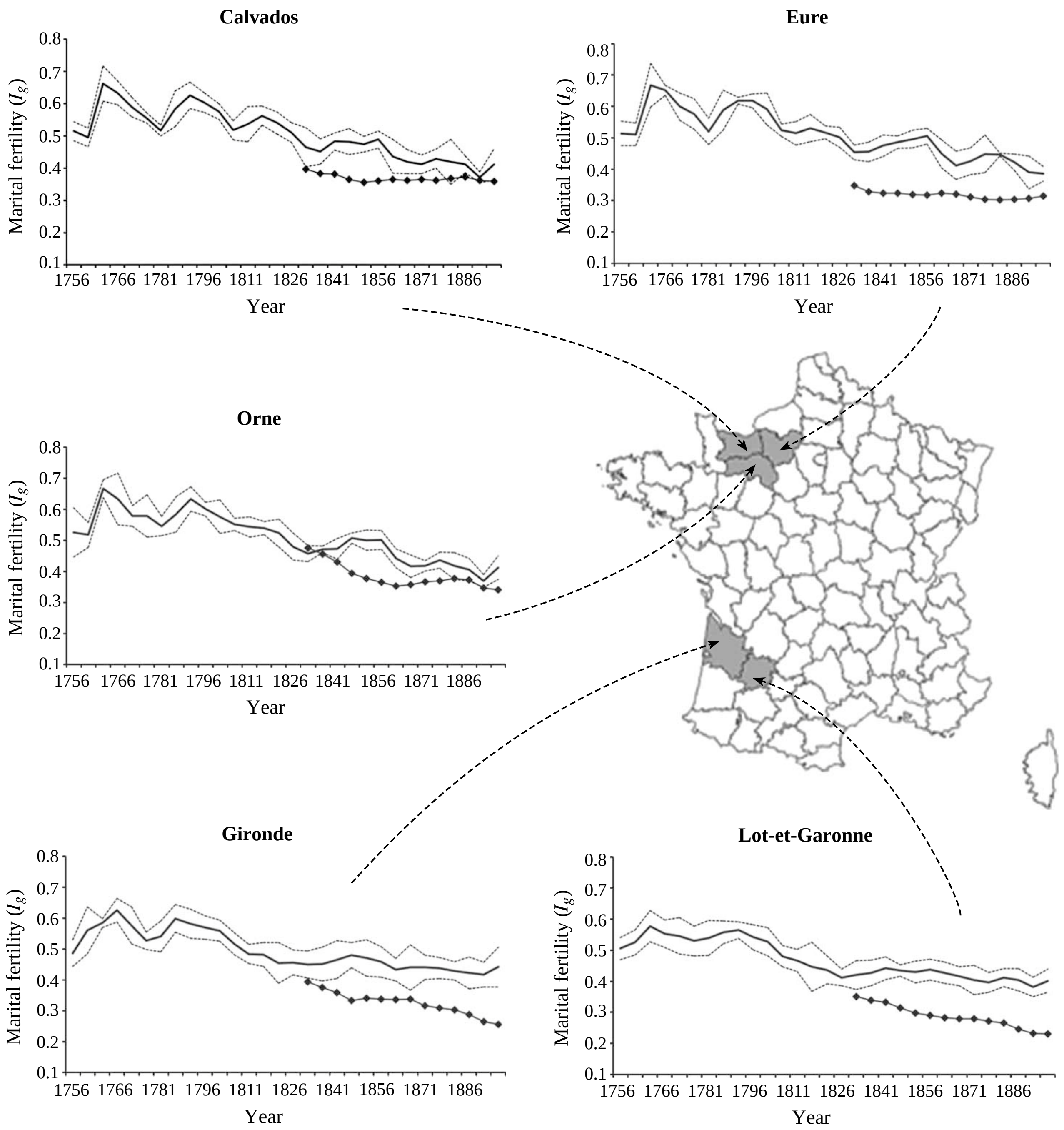

Figure 10 Actual and simulated marital fertility levels when $(\mu^{ar}, \mu^{mo}, \alpha, \gamma) = (1.50, 1.3, 0.7, 0.3)$, leading *départements*, France, 1740–1900
Notes: As for Figure 9.
Source: As for Figure 9.

areas the correlation might be good, in very liberal areas church leaders may have been motivated by political reasons to pressure priests into taking a stand *against* the Revolution as an example to their congregations. If this was the case, the impact of the Revolution on fertility could have been underestimated for areas leading the decline. In fact, it is interesting to note that, in contrast to the sluggish areas, which all had a high proportion of priests refusing to take the oath of allegiance to the Constitution, none of the *départements* leading the fertility decline held a high proportion of *réfractaires*. These effects may, of course, have been reinforced by other sources of heterogeneity, such as differences in income or education which are not incorporated into the model and are 'hidden' in the normal distribution from which agents draw their desired family size.

Conclusion

Recent literature has argued that agent-based simulation provides a fruitful avenue for the exploration of the individual-level mechanisms which underlie demographic trends (e.g., Billari and Prskawetz 2005; Hobcraft 2006, p. 176). Because they are anchored in various types of empirical information and make explicit assumptions about the factors behind agents' behaviour, simulation models are particularly useful as a means of testing theoretical arguments which cannot otherwise be investigated using available data. This paper has provided an example of the use of such models, demonstrating how they allow the impact of different assumptions about fertility-related behaviour to be traced, while also testing the relative weight of social interactions and social influence on those changes.

Fundamentally, the simulation exercise has been exploratory in nature, conducted in circumstances where a scarcity of data prevents the application of alternative empirical strategies. Nevertheless, our results provide evidence that emphasizes the relevance of social links and allowed us to reproduce observed patterns of fertility decline. Different combinations of parameters were able to replicate the observed demographic trends, although those simulations incorporating social interaction effects, via parameters α and γ, appeared to track population and fertility trends better than simulations where these effects were ignored. These findings imply that the contribution of inter-personal interactions should be considered when trying to explain fertility transitions. The role of such interactions has only been marginally discussed in the literature but, in light of our findings, it deserves further consideration.

The simulation models have also allowed us to test some hypotheses relevant to the debate on early modern demographic dynamics in France. For the pre-transitional period, and in contrast to the implication of many Malthusian arguments, the simulations suggest that families were *not* maximizing the number of their offspring. Further, the results contribute to an ongoing debate in the literature by implying that parents were probably considering the risk of their children dying when deciding how many to have. At the micro level the results also suggest that, in part, the different regional trends in fertility observed in France over the nineteenth and early twentieth centuries can be traced back to the heterogeneous impact of the Revolution. As envisaged by Sutherland (2003), and as interpreted in our model, the weakening of the Church by the Revolutionary authorities differentially affected the pre-Revolution, high-fertility norm. If this interpretation is correct, an interesting corollary of it emerges for the political economy of the Revolution. The Revolutionary government held the pro-natalist stance typical of many modern states that need people to pay taxes and fight wars; its success in dismantling the Church's structure may therefore have been Pyrrhic since in doing so it took to pieces the institution doing most to sustain high levels of fertility in France.

Although it has certain clear limitations, the simulation strategy proposed in this paper has been able to tackle many issues that other empirical methods have struggled to address. It is not a substitute for these methods, but a suitable complement to them, particularly in contexts where data are limited or theoretical modelling would be too complex for a tractable closed-form solution to be worked out.

Notes

1 Sandra González-Bailón is at Nuffield College, University of Oxford. E-mail: sandra.gonzalezbailon@nuffield.ox.ac.uk. Tommy E. Murphy is at Centro Dondena and IGIER, Università Commericiale Luigi Bocconi, Via Röntgen 1, 20136 Milano, Italy. E-mail: tommy.murphy@unibocconi.it

2 This work stems from research originally carried out by T. E. Murphy in his doctoral thesis (at the Department of Economics and Nuffield College, Oxford University) but both authors contributed equally to the current paper. An earlier version appeared in the Oxford Discussion Papers in Economic and Social History

Series (No. 71, 2008) under the title 'When Smaller Families Look Contagious: A Spatial Look at the French Fertility Decline using an Agent-Based Simulation Model'. The current version owes much to the feedback we received from the referees and editors of that series, from the reviewers for this Journal, and from discussions in several seminars (Nuffield College, University of Copenhagen, European University Institute, Università Bocconi, UBC, Dalhousie University, Paris School of Economics and University of Namur) and conferences (Economic History Society Meeting, World Congress of the International Institute of Sociology, World Congress of Cliometrics, the Conference of the European Social Simulation Association and the Conference of the European Historical Economics Society). For comments on earlier drafts we thank Marina Adshade, Gani Aldashev, Bob Allen, Michael Biggs, Francesco Billari, Jérome Bordieu, Mauricio Drelichman, Giovanni Federico, Price Fishback, George Grantham, David Green, Knick Harley, Eliana La Ferrara, Matthias Messner, Scott Moser, Avner Offer, Cormac Ó Gráda, Gilles Postel-Viney and Jacob Weisdorf.

References

Acemoglu, Daron, Davide Cantoni, Simon Johnson, and James A. Robinson. 2009. The consequences of radical reform: the French revolution. NBER Working Paper No. 14831.

Acemoglu, Daron, Davide Cantoni, Simon Johnson, and James A. Robinson. 2010. From Ancien Régime to capitalism: the French Revolution as a natural experiment, in J. Diamond and J. A. Robinson (eds.), *Natural Experiments in History*. Boston: Harvard University Press, pp. 221–256.

Bailey, Amy Kate. 2009. How personal is the political? Democratic revolution and fertility decline, *Journal of Family History* 34(4): 407–425.

Billari, Francesco and Alexia Prskawetz (eds). 2003. *Agent-Based Computational Demography*. Heidelberg: Physica-Verlag.

Billari, Francesco and Alexia Prskawetz. 2005. Studying population dynamics from the bottom-up: the crucial role of agent-based computational demography. Mimeo. Available: http://iussp2005.princeton.edu/download.aspx?submissionId=51988.

Binion, Rudolph. 2001. Marianne in the home: political revolution and fertility transition in France and the United States, *Population (English Selection)* 13(2): 165–188.

Bisin, Alberto and Thierry Verdier. 2001. The economics of cultural transmission and the dynamics of preferences, *Journal of Economic Theory* 97(2): 298–319.

Bocquet-Appel, Jean-Pierre and Lucienne Jakobi. 1998. Evidence for a spatial diffusion of contraception at the onset of the fertility transition in Victorian Britain, *Population (English Selection)* 10(1): 181–204.

Bonneuil, Noël. 1997. *Transformation of the French Demographic Landscape, 1806–1906*. Oxford: Clarendon Press.

Brown, John C. and Timothy W. Guinnane. 2002. Fertility transition in a rural, Catholic population: Bavaria, 1880–1910, *Population Studies* 56(1): 35–50.

Burch, Thomas K. 1996. Icons, straw men and precision: reflections on demographic theories of fertility decline, *Sociological Quarterly* 37(1): 59–81.

Caldwell, John C. 2004. Social upheaval and fertility decline, *Journal of Family History* 29(4): 382–406.

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

Casterline, John B. (ed.). 2001. *Diffusion Processes and Fertility Transition*. Washington, DC: National Academy Press.

Cavalli-Sforza, Luigi L. and Marcus W. Feldman. 1981. *Cultural Transmission and Evolution: A Quantitative Approach*. Princeton, NJ: Princeton University Press.

Chesnais, Jean-Claude. 1992. *The Demographic Transition: Stages, Patterns, and Economic Implications*. Oxford: Clarendon Press.

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

Coale, Ansley 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, NJ: Princeton University Press.

Derosas, Renzo and Frans van Poppel (eds.). 2006. *Religion and the Decline of Fertility in the Western World*. Dordrecht, the Netherlands: Springer.

Dumont, Arsène. 1890. *Dépopulation et Civilisation. Etude Démographique* [*Depopulation and Civilisation: Demographic Study*]. Paris: Lecrosnier et Babé—Libraires-éditeurs.

Durlauf, Steven N. and James R. Walker. 2001. Social interactions and fertility transitions, in J. B. Casterline (ed.), *Diffusion Processes and Fertility Transition*. Washington, DC: National Academy Press, pp. 115–137.

Flandrin, Jean-Louis. 1979. *Families in Former Times: Kinship, Household and Sexuality in Early Modern France*. Cambridge: Cambridge University Press.

Flinn, Michael W. 1981. *The European Demographic System, 1500–1820*. Baltimore, MD: Johns Hopkins University Press.

Friedlander, Dov, Barbara S. Okun, and Sharon Segal. 1999. The demographic transition then and now:

processes, perspectives, and analyses, *Journal of Family History* 24(4): 493–533.

Galor, Oded and David N. Weil. 1999. From Malthusian stagnation to economic growth, *American Economic Review* 89(2): 150–154.

Galor, Oded. 2005. From stagnation to growth: unified growth theory, in P. Aghion and S. N. Durlauf (eds.), *Handbook of Economic Growth. Volume 1A*. Amsterdam: North-Holland, pp. 171–293.

Garrett, Eilidh, Alice Reid, Kevin Schürer, and Simon Szreter. 2001. *Changing Family Size in England and Wales: Place, Class and Demography, 1891–1911*. Cambridge: Cambridge University Press.

Gibson, Ralph. 1989. *A Social History of French Catholicism 1789–1914*. London: Routledge.

Gille, H. 1949. The demographic history of the northern European countries in the eighteenth century, *Population Studies* 3(1): 3–65.

González-Bailón, Sandra and Tommy E. Murphy. 2013. Online Appendix to: Simulations of the effects of social influence on fertility decline in nineteenth-century France, *Population Studies* 67(2). Available: http://dx.doi.org/10.1080/00324728.2013.774435

Guinnane, Timothy W. 1999. Book review: Noël Bonneuil's Transformation of the French Demographic Landscape, 1806–1906, *Population and Development Review* 25(1): 169–174.

Guinnane, Timothy W. 2011. The historical fertility transition: a guide for economists, *Journal of Economic Literature* 49(3): 589–614.

Hajnal, John. 1965. European marriage patterns in perspective, in D. V. Glass and D. E. C. Eversley (eds.), *Population in History: Essays in Historical Demography*. Cambridge, MA: Blackwell, pp. 101–143.

Henry, Louis. 1961. Some data on natural fertility, *Eugenics Quarterly* 8(2): 81–96.

Henry, Louis. 1972. Fécondité des mariages dans le quart sud-ouest de la France de 1720 à 1829 [Marital fertility in the south-west quarter of France from 1720 to 1829], *Annales: Economies, sociétés, civilisations* 27(3 & 4/5): 612–639 & 977–1023.

Henry, Louis and Jacques Houdaille. 1973. Fécondité des mariages dans le quart nord-ouest de la France de 1670 à 1829 [Marital fertility in the north-west quarter of France from 1670 to 1829], *Population (French Edition)* 28(4/5): 873–924.

Henry, Louis and Yves Blayo. 1975. La population de la France de 1740 à 1860 [The population of France from 1740 to 1860], *Population (French Edition)* 30(Special issue: Demographie historique): 71–122.

Henry, Louis. 1978. Fécondité des mariages dans le quart sud-est de la France de 1670 à 1829 [Marital fertility in the south-east quarter of France from 1670 to 1829], *Population (French Edition)* 33(4/5): 855–883.

Henry, Louis and Jacques Houdaille. 1979. Célibat et age au mariage aux XVIIIe et XIXe siècles en France. II. Age au premier marriage [Celibacy and age of marriage in the eighteenth and nineteenth centuries in France. II. Age of first marriage], *Population (French Edition)* 34(2): 403–442.

Hobcraft, John. 2006. The ABC of demographic behaviour: how the interplays of alleles, brain, and contexts over the life course should shape research aimed at understanding population processes, *Population Studies* 60(2): 153–187.

Houdaille, Jacques. 1976. Fécondité des mariages dans le quart nord-est de la France de 1670 à 1829 [Marital fertility in the north-east quarter of France from 1670 to 1829], *Annales de Démographie Historique*, 341–392.

Iannaccone, Laurence R. 1992. Sacrifice and stigma: reducing free-riding in cults, communes, and other collectives, *Journal of Political Economy* 100(2): 271–291.

Iannaccone, Laurence R. 1998. Introduction to the economics of religion, *Journal of Economic Literature* 36(3): 1465–1496.

INED (Institut National d'Etudes Démographiques). 1977. Sixième rapport sur la situation démographique de la France [Sixth report on the demographic situation of France], *Population* 32(2): 255–338.

INSEE. 1961. *Annuaire Statistique de la France,* Nouvelle série -Rétrospectif-, 66(8), Paris.

Jones, P. M. 1988. *The Peasantry in the French Revolution*. Cambridge: Cambridge University Press.

Knodel, John and Etienne van de Walle. 1979. Lessons from the past: policy implications of historical fertility studies, *Population and Development Review* 5(2): 217–245.

Kohler, Hans-Peter. 2000a. Fertility decline as a coordination problem, *Journal of Development Economics* 63(2): 231–263.

Kohler, Hans-Peter. 2000b. Social interactions and fluctuations in birth rates, *Population Studies* 54(2): 223–237.

Kohler, Hans-Peter. 2001. *Fertility and Social Interaction: An Economic Perspective*. Oxford: Oxford University Press.

Le Play, Frédéric. 1874. *La réforme sociale en France déduite de l'observation comparée des peuples Européens—5 édition, corrigée et refondue* [*Social Reform in France coming from the Comparative Observation of the European People. 5th Edition, Corrected and Restated*]. Paris: Dentu.

Leroy-Beaulieu, Paul. 1896. *Traité théorique et pratique d'économie politique [Theoretical and Practical Treaty of Political Economy]*. Paris: Librairie Guillaumin et Cie.

Leroy-Beaulieu, Paul. 1913. *La question du la population*. Paris: Libraire Félix Alcan.

Lesthaeghe, Ron and Christopher Wilson. 1986. Modes of production, secularization, and the pace of the fertility decline in Western Europe, 1870–1930, in A. Coale and S. C. Watkins (eds.), *The Decline of Fertility in Europe: The Revised Proceedings of a Conference on the Princeton European Fertility Project*. Princeton, NJ: Princeton University Press, pp. 261–292.

Mason, Karen O. 1997. Explaining fertility transitions, *Demography* 34(4): 443–454.

Murphy, Tommy E. 2010. Old habits die hard (sometimes): what can *departement* heterogeneity tell us about the French fertility decline? IGIER Working Paper No. 364, Università Bocconi.

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: insight from longitudinal data for a Spanish town, *Population and Development Review* 33(4): 703–727.

Service de la Statistique Général de France. 1878. *Annuaire Statistique de la France* [*Statistical Yearbook of France*]. Paris: Imprimerie Nationale.

Spengler, Joseph J. 1938. *France Faces Depopulation*. Durham, North Carolina: Duke University Press.

Sutherland, Donald M. G. 2003. *The French Revolution and Empire: The Quest for a Civic Order*. Oxford: Blackwell.

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

Tackett, Timothy. 1986. *Religion, Revolution, and Regional Culture in Eighteenth-Century France: The Ecclesiastical Oath of 1791*. Princeton, NJ: Princeton University Press.

Van de Kaa, Dirk J. 1996. Anchored narratives: the story and findings of half a century of research into the determinants of fertility, *Population Studies* 50(3): 389–432.

Van de Walle, Etienne. 1974. *The Female Population of France in the Nineteenth Century*. Princeton, NJ: Princeton University Press.

Van de Walle, Etienne and Helmut V. Muhsam. 1995. Fatal secrets and the French fertility transition, *Population and Development Review* 21(2): 261–279.

Van de Walle, Francine. 1986. Infant mortality and demographic transition, in A. J. Coale and S. C. Watkins (eds.), *The Decline of Fertility in Europe: The Revised Proceedings of a Conference on the Princeton European Fertility Project*. Princeton, NJ: Princeton University Press, pp. 201–234.

Voigtländer, Nico and Hans-Joachim Voth. 2010. How the West 'invented' fertility restriction. Mimeo. Available: http://www.anderson.ucla.edu/faculty/nico.v/Research/EMP.pdf

Weir, David R. 1983. Fertility transition in rural France, 1740–1829, PhD dissertation, Stanford University.

Weir, David R. 1984. Fertility transition in rural France, *Journal of Economic History* 44(2): 612–614.

Weir, David R. 1994. New estimates of nuptiality and marital fertility in France, 1740–1911, *Population Studies* 48(2): 307–331.

Wrigley, E. Anthony and Roger S. Schofield. 1981. *The Population History of England 1541–1871—A Reconstruction*. Cambridge: Cambridge University Press.

Wrigley, E. Anthony. 1985a. The fall of marital fertility in nineteenth-century France: exemplar or exception? (Part I), *European Journal of Population* 1(1): 31–60.

Wrigley, E. Anthony. 1985b. The fall of marital fertility in nineteenth-century France: exemplar or exception? (Part II), *European Journal of Population* 1(2/3): 141–177.