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Research Article

Examining the relationships between education, coresidential unions, and the fertility gap by simulating the reproductive life courses of Dutch women

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Abstract

BACKGROUND
Couples in Europe have fewer children than they intend to, resulting in a gap between intended family size and completed fertility. This is partly because first-pregnancy attempts are postponed to older reproductive ages, when giving birth is more difficult due to the decline in fecundity and increased probability of miscarriage. Modelling educational differences in prevalence, timing, and stability of coresidential unions together with reproductive behaviour and constraints provides us with information on how postponement relates to completed fertility.

OBJECTIVE
We measure the extent to which changes in education, union events, and physiology change the gap between intended family size and coresidential completed cohort fertility for Dutch women born during 1974–1984.

METHODS
We perform microsimulations including physiological parameters and detailed information on education and union events. Our model parameters are based on a range of representative data sources, including the Generations and Gender Survey and the Longitudinal Internet studies for the Social Sciences panel.

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RESULTS
Counterfactual simulations revealed that increases in lifelong singlehood increased the fertility gap the most, followed by separation and divorce. Re-partnering rates reduced the gap slightly more than marriage rates. Highly educated women had larger fertility gaps, mainly because they cohabited less and later than low-educated women.

CONCLUSIONS
Lifelong singlehood and increasing ages at entry into first coresidential union should receive more attention, given their strong positive associations with the fertility gap.

CONTRIBUTION
We are able to model and measure the degree to which education, unions, and physiology are associated with the gap between intended family size and completed cohort fertility. We advance existing microsimulation fertility models.

1. Introduction

Couples across Europe are having fewer children than they intend to, resulting in a gap between intended family size (the total number of children the couple intends to have) and completed cohort fertility (the average number of children women in a specific birth cohort have). The average size of this gap for women born in the 1960s–1970s was 0.28 in 18 EU countries and the United States, with the Netherlands being close to the average (Beaujouan and Berghammer 2019; Testa 2014).

A large part of the fertility gap is likely attributable to postponement of first-pregnancy attempts to increasingly older ages, when physiological constraints reduce the probability of pregnancy and live births (Magnus et al. 2019; Sauer 2015). The expansion of higher education among women and the decline in union stability over the past few decades are considered two important contributors to this postponement (Andersson et al. 2022; Ní Bhrolcháin and Beaujouan 2012; Winkler-Dworak et al. 2017). Highly educated women in particular invest more time and resources in their education and career development, which means that they face opportunity costs of having children early in their careers, even in countries with progressive family policies (Adda, Dustmann, and Stevens 2017; Connolly and Gregory 2009; Doepke et al. 2022; Gjerdingen et al. 2001).

Non-marital cohabitation[4] has become increasingly common over the past decades. The link between marriage and childbirth has also weakened, and has resulted in a rapid

[4] In this paper ‘cohabitation’ is reserved for non-marital coresidential unions and ‘marriage’ for marital coresidential unions. ‘Coresidential union’ is used when referring to both non-marital and marital coresidence.

increase in the share of births that occur outside marriage in countries like the Netherlands (6% in 1982, 58% in 2022) (CBS 2023a). The weakening link between marriage and childbirth, together with the fact that the probability of separation[5] is higher and occurs earlier in the life course (Coleman 2013; Jalovaara and Andersson 2023; Jalovaara and Kulu 2018; Perelli-Harris et al. 2017), has increased the probability of union dissolution (Kalmijn and Leopold 2021). This, in turn, has made re-partnering and multi-partner fertility (Thomson, Gray, and Carlson 2020) more common over time. It is therefore important to include both non-marital coresidential unions and re-partnering when studying recent fertility patterns in Europe.

In this study we focus on how education and union patterns contribute to the fertility gap through postponement of childbirth and physiological constraints on fertility. We also decompose the educational gradient in the fertility gap (CBS 2017; Nisén et al. 2021) and perform some tentative future projections. We develop a microsimulation model which allows us to model and compare the contributions[6] that changes in educational structure and union events make to the size of the fertility gap. The aim is not to produce a perfect model for causal interpretation, but a detailed model including important determinants of fertility that can give us insights into the fertility process.

Our model generates reproductive life courses of Dutch women born between 1974 and 1984. This cohort was chosen because we needed information on the women's intended family size early in their reproductive lives and their completed fertility in order to measure the gap between the two. We construct the simulation model with information on the intended family size and educational attainment of the women, as well as detailed information on union formation and dissolution and the reproductive process. We use data from the Generations and Gender Survey and the Longitudinal Internet studies for the Social Sciences panel, together with other sources. The model is validated using cohort fertility data from the Human Fertility Database (HFD) and reports by Statistics Netherlands (CBS). We measure the contributions of union events and physiology to the gap between intended family size and completed cohort fertility across women with different levels of educational attainment.

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[5] 'Separation' is reserved for the dissolution of a non-marital coresidential union, while 'divorce' is reserved for the dissolution of a marriage.

[6] By the term 'contribution' we do not mean a casual effect or impact, but rather the proportion of change in our outcome of interest – the fertility gap – that is attributable to a particular parameter change based on our counterfactual simulations. Endogeneity is present in the relationship between union event and fertility outcome where entry into a coresidential union may increase the probability of conception, but conception may also increase the probability of entry into a coresidential union. For instance, women with a strong desire to form a family can also be selected into coresidence or marriage. We are prevented from modelling such cases of reverse causality due to a lack of data and the structure of our simulation model. Our broader parameters and their contributions therefore have more detailed interconnected mechanisms at lower levels of abstraction that we are unable to account for and we cannot isolate the causal pathway between our parameters and the fertility gap. We can only draw conclusions from the set of parameters and mechanisms we include at the level at which we model them.

Our microsimulation model makes the following contributions to fertility research. First, we explicitly model the age-related physiological constraints on human reproduction (fecundability, intrauterine mortality, sterility). We therefore address the fact that age-related physiological constraints on fertility mediate the effects of more distant fertility determinants like education and union status. Deliberate control over reproduction (contraception, induced abortion) is also modelled. Second, we are able to model how the relationships between education, union patterns, and the physiological parameters produce fertility outcomes over the life courses of women. Modelling such a complex set of transitions, some of which are not Markov chains (e.g., waiting times to conception, intended family size and contraception) is not possible using alternative methods for generating hypothetical life courses, like multistate life tables (Thomson et al. 2012). Third, in dynamic microsimulation models like the one we have constructed, both the timing (across/at which ages) and magnitude (by how much) of parameters to produce different counterfactual simulations can be flexibly adjusted. These simulations, for instance, can be used to estimate how influential certain parameters are in processes, as we do in our study. Lastly, our simulation model bridges the gap between previous microsimulation models that have modelled either the physiological constraints on human reproduction in detail (Ciganda and Todd 2021; Eijkemans et al. 2014; Habbema et al. 2015; Leridon 2004; Leridon and Shapiro 2017) or union dynamics in detail (Thomson et al. 2012; Thomson, Winkler-Dworak, and Beaujouan 2019; Winkler-Dworak et al. 2017, 2021), by including both these aspects, as well as education.

2. Background

We study how postponement of childbirth relates to the fertility gap because we are interested in knowing which factors make achieving fertility intentions difficult for couples. Age is a key variable in this association, but the mechanisms between age and fertility outcomes are rarely modelled explicitly. By modelling age-related constraints on couples' biological ability to conceive and give birth, together with partnering- and contraceptive behaviour, and by conducting counterfactual simulations, we can estimate how much each parameter we consider is expected to change the size of the fertility gap.

There are a few reasons why we choose to focus on union formation, union dissolution, and educational attainment in this study. First, separation and divorce have become increasingly common among more recent cohorts (Jalovaara and Andersson 2023; Kalmijn and Leopold 2021; Kreyenfeld and Trappe 2020: 6). This also means that an increasing share of fertile-age adults are re-partnering, and that births from these re-partnerships are increasing as a share of total births. We need to account for these dynamics to accurately simulate modern fertility patterns. Second, educational differences have been observed in completed fertility, childlessness, and the timing of first births across Europe (Jalovaara et al. 2019; Miettinen et al. 2015; Nisén et al. 2021). Third, time spent in education is associated with the timing of first birth (Ní Bhrolcháin and Beaujouan 2012; Raymo et al. 2015), because we can assume that few women have a child during enrolment in education.[7]

2.1 Union formation and fertility

Despite an increase in births to single mothers, the vast majority of births in the Netherlands still occur within coresidential unions (93% in 1996, 89% in 2022) (CBS 2023a). Historically, there has been a positive relationship between childbirth and marriage (Andersson et al. 2022; Baizán 2003; Baizán, Aassve, and Billari 2004; Brown and Dittgen 2000), with conceptions tending to peak shortly after marriage. Non-marital births have, however, been rapidly increasing as a share of all births in the Netherlands (CBS 2023a), which has weakened the association between marriage and childbirth. While entry into a coresidential union has been found to be both a cause and a consequence of the intention to have children (Baizán 2003; Baizán, Aassve, and Billari 2004), our methodology limits us to studying only the relationship running from union formation to childbirth.

2.2 Union dissolution, re-partnering, and fertility

Cohabitation has become increasingly common over the past decades across Europe, in tandem with the relative decline in marriage and increase in divorce (Coleman 2013; Jalovaara and Andersson 2023; Perelli-Harris et al. 2017). While cohabitation is still largely considered a step towards marriage, in Western and Northern Europe it is also becoming an alternative to marriage, and cohabitation rates are high (Hiekel, Liefbroer, and Poortman 2014). Marriage is still a more stable form of union than cohabitation, as the probability of separation is higher than the probability of divorce (Jalovaara and Kulu 2018; Kalmijn and Leopold 2021). Low fertility (and childlessness) is therefore linked to singlehood and fragmented cohabitation (Jalovaara and Fasang 2017).

[7] The mean share of births in the Netherlands 2000–2020 was less than 1% at ages below 20 and less than 8% at ages 20–25 (CBS 2023c). Almost all of the <8% of births below ages 20–25 were to low- and medium-educated mothers (van Duin and Feijten 2023: 3.2.2). As the expected ages at graduation for our educational categories were 18 (low), 20 (medium), and 22 (high), childbearing among women enrolled in education must have been very rare. Early childbirth could also present an obstacle to higher education among women (Cohen, Kravdal, and Keilman 2011), although this link is less studied and our modelling approach limits us to study the relationship going from education to childbirth, but not the other way around.

With more frequent union dissolutions, re-partnering is becoming an increasingly important factor in fertility analysis, although multi-partner fertility as a share of total fertility is still low in Europe, ranging between 4% and 12% across 13 EU countries[8] (Thomson, Gray, and Carlson 2020). Studies using European data have found that the probability of having another child is somewhat higher for re-marrying mothers than mothers of the same parity (number of children) staying in the same relationship. However, there is little evidence that re-partnering would completely replace fertility lost due to union dissolution. Plausible explanations for this are the physiological constraints on fertility that women face at older reproductive ages, re-partnering being mostly nonmarital, and mothers with dependent children being less likely to re-marry (Andersson et al. 2022; Ivanova, Kalmijn, and Uunk 2014; Thomson et al. 2012; Vanassche et al. 2015; Winkler-Dworak et al. 2017). Due to a lack of reliable estimates of how much more likely births are in re-marriage, and how much less likely re-marriage is by parity, we did not explicitly model these mechanisms.[9]

2.3 Education, career, partner preference, unions, and fertility

In the Netherlands, low-educated women in the 1966–1970 birth cohort had on average 0.18 more children[10] than highly educated women (Nisén et al. 2021). This difference is likely related to two things in particular. First, highly educated women have been found to be less likely to ever enter a coresidential union across Europe (Bellani, Esping-Andersen, and Nedoluzhko 2017),[11] something we also find in our sample cohort (Table 3). Second, highly educated women in our sample had their first cohabitation considerably later than low-educated women (Table 3), which is likely connected to three factors: enrolment in education, career formation, and partner preference.

First, highly educated women spend more time enrolled in education, which may delay cohabitation (with a romantic partner) and childbirth (Ní Bhrolcháin and Beaujouan 2012), as these are rare during enrolment. Highly educated women also invest more resources in their education and career. Temporary absence from the labour market and part-time work early in their career risk a loss of future income and the opportunity of promotion. Despite childcare having become more privatised, the labour market being more flexible, and household work more evenly split between the sexes, opportunity costs still influence the timing of cohabitation and first birth – for highly educated women in

[8] 7.8% of total births in Belgium, no estimate for the Netherlands
[9] Regardless, their contribution to completed cohort fertility is likely small, given that only 58% of unions resulted in marriage and multi-partner fertility as a share of total fertility was most likely below 10%.
[10] 1.89 versus 1.71
[11] European Social Survey (ESS) data 2002–2014, European Value Study (EVS) 2008–2009 data. Women ages 40–55 (Bellani, Esping-Andersen, and Nedoluzhko 2017).

particular (Adda, Dustmann, and Stevens 2017; Connolly and Gregory 2009; Doepke et al. 2022; Gjerdingen et al. 2001; Verweij et al. 2021). The Netherlands stands out in Europe when it comes to employment-related opportunity costs for women, having the highest rates of female part-time employment in the EU (Eurostat 2024). This part-time employment is strongly linked to entry into motherhood, but even before becoming mothers Dutch women have 2–3 times higher part-time employment rates than men, with an increase between singlehood and cohabitation (CBS 2023d). Hence, while Dutch women are subject to career-related opportunity costs, they also seem to have a stronger preference for part-time employment than Dutch men. Third, a large survey of human mate preferences suggests that women prefer ambitious and industrious partners with high earning capacity (Buss 1989; Buss and Schmitt 2019). Educational attainment is closely connected with these traits (Dumfart and Neubauer 2016; Griliches and Mason 1972; Jencks and Others 1979; O'Connell and Marks 2022), which suggests that women tend to look for partners with an educational attainment at least as high as their own. However, the share of women with a high education now exceeds the share of men with a high education in most of Europe (CBS 2023b; Eurostat 2023; UNECE 2023). Although hypogamy (wife having higher education than husband) has now become more common in Europe than hypergamy (husband having higher education than wife), this shift likely reflects the increasing gap between the share of highly educated women and men, rather than a shift in women's preferences (Erát 2021; Van Bavel, Schwartz, and Esteve 2018). Highly educated women may therefore experience greater difficulty finding a long-term partner. Indeed, among recent cohorts of young adults in Europe a higher observed increase in singlehood shortly after leaving the parental home has been observed for women than for men. A positive educational gradient in singlehood has also been found to be stronger for women than for men (van den Berg 2023; van den Berg and Verbakel 2022).

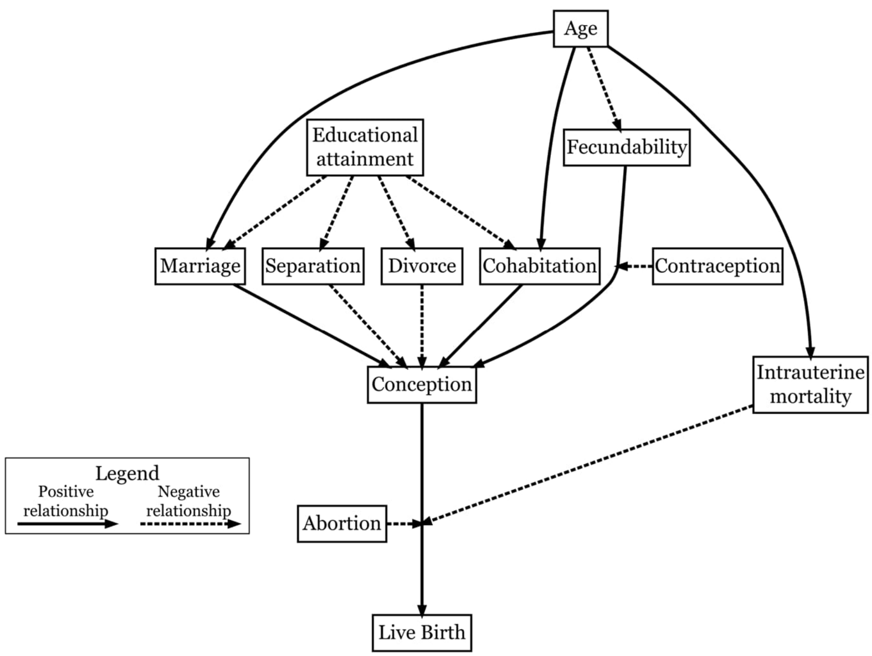
More time spent enrolled in education, greater investment in and emphasis on career formation, and highly educated women having greater difficulty finding a long-term partner are therefore likely explanations for their less frequent and later entry into first coresidential union in our sample cohort. While we model how education influences union formation and dissolution, we have not explicitly modelled career trajectories.

2.4 Human reproduction and contraceptive use

The physiology behind human reproduction is complex and has to be simplified for the purpose of modelling this process. Following demographic modelling work by Louis Henry (Henry 1953, 1961, 1964) and Henri Leridon (Leridon 1977), among others, we simplify the physiological components of human reproduction to fecundability (the monthly probability that a couple has a successful conception), age at sterility, intrauterine mortality (foetal death at any point during the pregnancy), and the non-susceptible period (the period after a conception has terminated during which the woman does not ovulate). These components alone may be sufficient when studying natural fertility[12] populations, but in modern populations contraception plays an important role. To model contraception we therefore include information on both the duration and efficacy of spacing (contraception before and between intended conceptions), stopping (contraception after the intended family size has been reached), and induced abortion (unintended conceptions). The physiological and contraceptive components of the model are discussed in more detail in the data section, as these components are mathematically derived from various historical sources or empirically estimated from available surveys and registers, rather than based on behavioural theory and research.

The conceptual framework of this paper, which summarises the theoretical and empirical discussion in the literature review, is depicted in Figure 1.

Figure 1: Conceptual framework



Note: Fecundability is the monthly probability of conceiving a child, intrauterine mortality is foetal death at any point during pregnancy.

[12] Populations that do not consciously use contraceptive methods to limit their fertility

3. Methodology

Our simulation is a Monte Carlo microsimulation, which means that randomly drawn numbers are compared to transition probabilities to determine transitions between states. If the conditions of a transition between two states is met the event occurs; if not, the woman stays in her present state. There are numerous similarities, dissimilarities, advantages, and disadvantages between more commonly used macro-level population projection methods like the cohort-component method and microsimulation approaches like the one we use. For a detailed discussion on the topic refer to van Imhoff and Post (1998); for a historical overview of modelling of the reproductive process in demography see Ciganda and Todd (2021) .

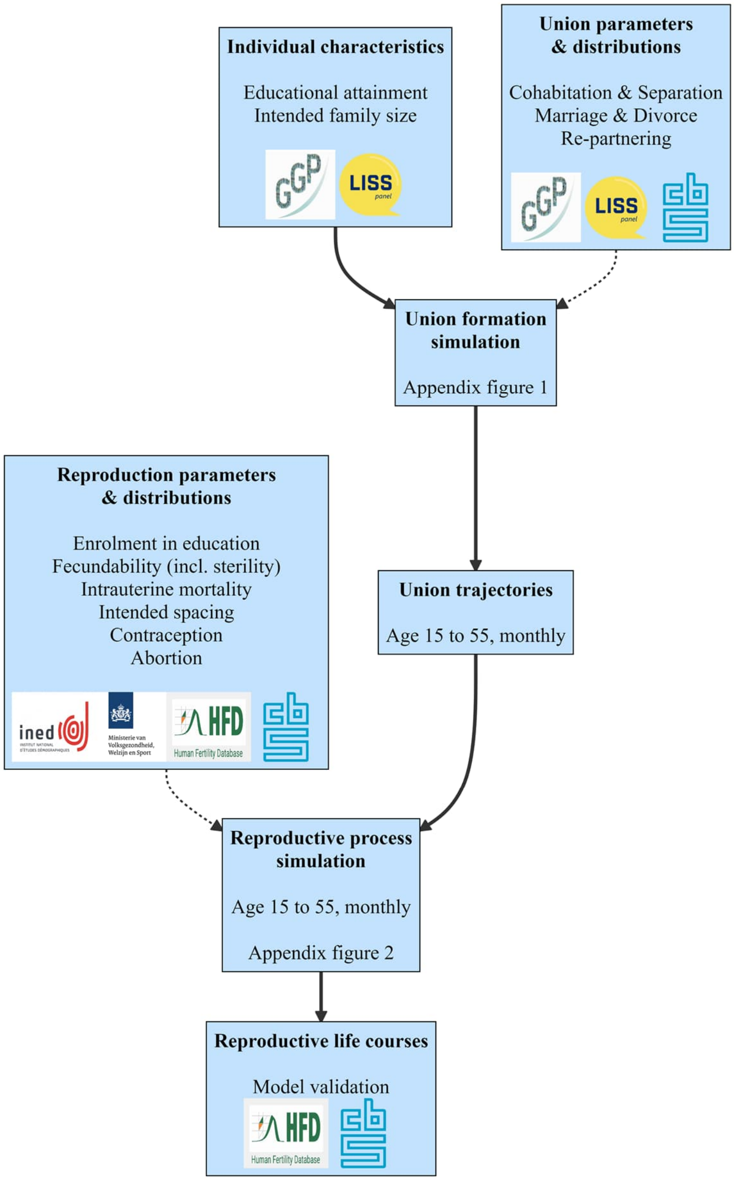
Our 'LIFERT' simulation model was built in R and extends modelling work by Henry Leridon (Leridon 1977, 2004, 2008; Leridon and Shapiro 2017). We include several additional parameters in our model (cohabitation, separation, re-partnering, education, abortion etc.), while not including assisted reproductive technologies (ART), which Leridon's model does (Leridon and Shapiro 2017).

The simulation is split into two parts: the union trajectories and the reproductive process. As the latter depends on the former (women only conceive within coresidential unions in our model and waiting time to conception is based on when they enter a coresidential union), the union simulation is run first. Our simulation models are run for individual women. Since we sample 100,000 women, the simulations run 100,000 times[13] each. The models iterate monthly to follow the menstrual cycle, which is estimated to be 29.3 days on average based on recent Swedish, UK, and US data (Bull et al. 2019). They run from age 15 to age 55, covering the entire reproductive life course of a woman. An overview of the simulation is depicted in Figure 2, with detailed descriptions in Figures A-1 and A-2 (Appendix).

One important advantage of our microsimulation approach is the ability to model, test, and measure the magnitude of relationships at the level of the individual across the life course. The output is therefore a sequence of events – a life course. We can then perform counterfactual ('what if…') analyses over the life course, which can be useful for testing where and when policy measures may be effective. Compare this with regression analysis where the output is one or more coefficients that give us a point estimate of the relationship between two or more variables. This is not to say that one is better than the other: constructing an empirically calibrated simulation model relies on established relationships, usually derived from regression analyses. The methods are complementary, with different use cases.

[13] 100,000 times was deemed sufficient as the variation from the mean in cohort fertility and the fertility gap between simulation runs was small [–0.0011, 0.0009] based on 10 base model simulation runs with a sample size of 100,000 in each run.

Figure 2: Overview of the simulation process (details in Appendix Figures A-1 and A-2)



Simulation can also partially address the problem of data scarcity. We lack complete information on many events that take place across the life course of an individual. However, by simulating from population-representative distributions and validating the simulation outputs against different representative estimates we can produce realistic representations of reality. In theory, microsimulation could address issues of endogeneity, multicollinearity, and autocorrelation that are often present in statistical analysis (Legendre 1993; Roberts and Whited 2013: 7; Vatcheva et al. 2016), but this would require very detailed data, knowledge of all the relevant mechanisms, and highly complex modelling. Our approach is instead to construct a less detailed (but still complex) simulation model. We explicitly model important mechanisms, and draw conclusions at the level of detail at which we are able to model. This also means that our model is not causal, because we are unable to model all relevant mechanisms, including potential reverse causation. Examples of this are selection into marriage based on childbearing intentions, or the influence of personal characteristics like personality, religion, etc. on fertility behaviour.

4. Data

We discuss the model inputs in this section, with details provided in the data description table (Table 1). For most of the behavioural parameters we used data from the Generations and Gender Survey (GGS) Wave 1 (Gauthier, Cabaço, and Emery 2018; Generations And Gender Programme 2019) and the Longitudinal Internet studies for the Social Sciences (LISS) panel administered by Centerdata (Tilburg University, The Netherlands). GGS is a widely used series of panel surveys of the life course trajectories of adults, with information on a range of personal characteristics and interpersonal relationships. We used data from the first edition of the survey in the Netherlands, and the first wave of that survey conducted in 2003. We restricted our sample to Dutch women born during 1974–1984[14] with a reported level of education. The LISS panel is a population-representative panel consisting of several questionnaires with repeated measurements of different aspects of the life course. We use data from the first 15 waves (2008–2022) of the Family and Household questionnaire and information on education from the LISS background variables. Other sources we use are discussed in the data description table and the sub-sections below.

[14] In some cases we extend this range to 1954–1984 or used the 1954–1964 cohort, due to small sample sizes or incomplete data. See descriptive data table for details.

4.1 Intended family size

Fertility intentions tend to change with age and parity. It is therefore useful to distinguish between family size and parity-progression intentions (intention to have another child). The former can be thought of as a maximum limit on the number of children, as this limit is most often underachieved or adjusted downwards rather than upwards (Berrington and Pattaro 2014; Morgan and Rackin 2010) over the reproductive life course. The latter is a shorter-term probability of having a(nother) child, and is therefore less prone to adjustment and more useful for short-term prediction (Balbo, Billari, and Mills 2013). Fertility intentions also involve different degrees of uncertainty depending on factors such as whether the woman has a partner, the number of children she intends to have, disagreement in preferred family size between partners, or whether she even has a preferred family size to begin with (van Tintelen and Stulp 2024; Xu et al. 2024).

There are a few reasons why we use the intended family size rather than parity progression intentions in our model. First, we are interested in the difference between the total number of children a woman has at the end of her reproductive life and the number of children she intended to have – the fertility gap. Second, the way in which we model contraceptive behaviour (spacing/stopping) requires that we assign an intended family size to each woman. Third, there is no representative longitudinal survey data on parity progression intentions in the Netherlands,[15] which we would need in order to update the intended family size over the life course. Fourth, even if such data were available, fertility intentions are adjusted over the life course based on the experiences of the individual (Hayford 2009; Nitsche and Hayford 2020). If we chose fertility intentions at more advanced reproductive ages we might end up with a gap close to 0, because at older reproductive ages the woman has either had the number of children she intended to have or knows that achieving her desired family size is unrealistic. As the intended family size serves as a maximum limit to fertility in our modelling approach, and because we are interested in factors influencing the fertility gap, it makes more sense to use a measure from earlier in the reproductive life of a woman, before the influence of decisions and circumstance.

We used information on intended family size recorded at ages 19–29 (GGS I, 2003) and 24–34 (LISS Family and Household wave 1, 2008).[16] The GGS distribution for

[15] There are three waves of GGS I (2003, 2006, 2010) for the Netherlands, but attrition is high (50% of the sample lost between waves 1 and 3) and the response rate to the question ‘Do you intend to have a/another child during the next three years?’ is low, with less than half of respondents answering the question in wave 1 and only one quarter answering it in wave 3. It is therefore not possible to extract a representative distribution of parity progression ratios for the 1974–1984 cohort from this data.

[16] The upper limit at age 34 for the LISS sample is a bit high, but when combined with GGS data the distribution is indistinguishable from when the LISS age range is limited to 24–29-year-old women. The 24–34 age range was chosen for consistency and a larger combined sample size (1,099 versus 759).

intended family size was generated by summing the number of additional children the woman wanted to have and the number of biological children she had already given birth to at the time of the survey. If she responded that she did not want to have more children, her intended family size was her current number of biological children. For LISS the principle was the same.[17] There was no noticeable difference in intended family size between educational groups, which is why we did not stratify intended family size by education.

4.2 Fecundability

Fecundability is the probability that a couple produces a conception during a particular month, even though we refer to individual women in the simulation. Given that there was no information on the male partner in the fertility data we used, and because male fecundability is not yet well understood (Harris et al. 2011; Wang and Swerdloff 2014), it would not have been feasible to try to separate the two in our simulation model. However, it is known that the female partner's contribution to fecundability is more important than that of the male partner (Eijkemans et al. 2014).

Based on work by Louis Henry (1961, 1964) and Henri Leridon (1977, 2017), we chose a beta distribution to represent maximum (peak) fecundability (Leridon 1977: 30–36; Leridon and Shapiro 2017). There have been more recent attempts at estimating fecundability from different contemporary data sources (Dunson, Baird, and Colombo 2004; Rothman et al. 2013; Wesselink et al. 2017) using Bayesian (Dunson 2001) and life table methods. While these studies seem to suggest that historical estimates of fecundability may be somewhat underestimated, the fertility outcomes produced by our model are not particularly sensitive to changes in the mean of the fecundability distribution.[18]

To account for the fact that a woman's fecundability declines during her later reproductive years, we assumed a linear decline from the woman's maximum fecundability that starts 12.5 years before the age at which she reaches permanent sterility. This assumption is based on Leridon's early work on rank and final number of births using French historical data (Leridon 2023, personal communication, 23 February). More recent attempts to estimate this decline, both formally and statistically, have also yielded near-linear declines (Larsen, Yan, and Yashin 2003; Wesselink et al. 2017; Yan

[17] However, the question about fertility intentions was how many more children the woman thought she would have in the future

[18] A change in the mean fecundability from 0.25 (beta distribution with $a = 3$, $b = 9$) – which is already considered a high estimate of fecundability (Leridon 1977: 36–37; Leridon and Shapiro 2017) – to 0.3 (beta distribution with $a = 4$, $b = 9$) decreased the fertility gap for the cohort we simulated by less than 0.02 children.

and Larsen 2001). Moreover, the assumption of a gradual decline in fecundability is supported by the fact that ovulation becomes less frequent at older reproductive ages (O'Connor, Holman, and Wood 1998; te Velde and Pearson 2002).

4.3 Intrauterine mortality

Intrauterine mortality is the death of the foetus at any point during pregnancy. Based on the data available at the time, Leridon (1977) estimated the probability of intrauterine mortality that is detectable without special methods to be around 15%, which matches recent estimates of miscarriage among clinically confirmed pregnancies. We use Leridon's (1977) age distribution for intrauterine mortality in our simulation model (Andersen et al. 2000; Laisk et al. 2020; Leridon 1977: 62–63). Leridon refers to observable mortality at all gestational ages, whereas miscarriage is defined as observable mortality up to weeks 20–22. His estimate therefore includes foetal mortality, deaths before or during birth at or after 22 completed weeks of gestation. These are, however, far less common than miscarriage at around 6.6–7.4‰ (per thousand) in the Netherlands, so they do not influence the 15% estimate (Mohangoo et al. 2011). An estimated 80% of intrauterine deaths occur during the first trimester, which we account for in our model (Dugas and Slane 2023; Wilcox et al. 1988).

4.4 Non-susceptible period

The non-susceptible period is the period after a live birth, miscarriage, or abortion during which the woman does not ovulate. The duration of the non-susceptible period depends first, on whether the conception ends in a live birth or not. Second, it depends on the duration of breastfeeding or post-partum abstinence (whichever is longer), as breastfeeding induces temporary infertility (lactational amenorrhea) and abstinence naturally reduces the probability of conception to zero. As we found no information on postpartum abstinence, we estimated the non-susceptible period distribution based on recent survey data (Theurich et al. 2019) on breastfeeding rates among Dutch women[19] and the mean duration of amenorrhea by duration of breastfeeding of French women calculated by Leridon (1977) (Leridon 1977: 83).

[19] Although we found a data source that stratifies breastfeeding rates by education (Peeters, Lanting, and van Wouwe 2015), the difference between low- and high-educated women was no larger than 10 percentage points. As the duration of postpartum amenorrhea is shorter than the intended spacing for the first and second child and in most cases the third child as well (42, 15, and 5 months versus truncated normal distribution with a mean of 4 and a minimum of 0), the educational difference in the postpartum duration would not have significantly changed our results, at the cost of added model complexity and data demands.

4.5 Age at permanent sterility

The age at permanent sterility is the age at which a woman is no longer able to become pregnant. We used the age-at-sterility curve empirically estimated by Leridon (Leridon and Shapiro 2017) based on the biological age-at-last-birth curve estimated by Eijkemans et al. (2014), which in turn is based on historical data[20] from a number of non-contracepting (natural fertility) populations. Natural fertility data is necessary to rule out the influence of contraceptive use and induced abortion, which distort sterility estimates (Eijkemans et al. 2014; Leridon and Shapiro 2017).

4.6 Intended spacing and contraception

In contexts with widespread use of contraceptives such as the Netherlands, we need to account for the couple's desired spacing between coresidential union and childbirth as well as between births. How we calculated these durations of intended spacing is outlined in Table 1. We also estimated contraceptive efficacy rates, in terms of both spacing and stopping. The ratios between the spacing and stopping parameters were based on estimates of Dutch women's reported contraceptive use within relationships in 2013 (CBS 2014) and Leridon's estimate of contraceptive use among French women in 1978–2000, respectively (Leridon and Shapiro 2017; Rossier, Leridon, and The COCON Group 2004).

[20] There is some evidence that the mean age at menopause increased and the age at menarche declined during the 1900s, resulting in a slightly wider reproductive window (Appiah et al. 2021; Gottschalk et al. 2020). However, empirical evidence suggests that with the introduction of effective contraceptive methods like the pill, the trend among women has been to end their reproductive period earlier (stopping) (Eijkemans et al. 2014). We can assume that this possible increase in the reproductive window has had little effect on fertility given that the mean age at first birth has been steadily increasing, meaning that the years added to the reproductive window are concentrated at older reproductive ages.

Table 1: Description of the data

Parameter	Sample size	Processing/information	Format
Fecundability	–	Beta distribution (a = 3, b = 9, mean ≈ 0.25), 12.5 years of linear decline before age at sterility (Leridon 2004, 2017)	Pseudo-randomly generated from distribution
Intrauterine mortality	–	Fitted third degree polynomial distribution to values estimated by Leridon (1977: 61–66), Month of miscarriage distribution based on clinical data[1]	Same distribution for all women, sampling from month of miscarriage distribution
Non-susceptible period	–	Live birth: truncated normal distribution[2] (mean = 4, lower = 0), miscarriage & abortion:[3] 1 month	Live birth: sampling from distribution, miscarriage, & abortion: same for all women
Age at permanent sterility	–	Cubic spline interpolation between yearly data points from Leridon (Leridon and Shapiro 2017), sampling from distribution	Sampling from distribution
Intended spacing	–	9 months of pregnancy + 5 months[4] waiting subtracted from the difference between the mean age at first cohabitation and the mean age at first birth, and HFD birth interval differences	Same distribution for all women
Spacing & stopping contraception	–	spacing: 98.2% efficacy ages 15–25, 96.2% ages 26–55[5] stopping: 99.1% efficacy based on Leridon (Leridon and Shapiro 2017)	Same for all women
Unintended pregnancy	–	Unintended pregnancies ≈ 20%[6]	Same for all women
Abortion	–	58% probability, abortion ratio (154 abortions per 1,000 live births, years 2000–2020) and month of pregnancy in which abortion occurred set to match official statistics[7]	Same for all women

[1] (Dugas and Slane 2023; Wilcox et al. 1988), [2] (Leridon 1977: 83; Theurich et al. 2019), [3] (Donnet et al. 1990; Schreiber et al. 2011), [4] 5 months based on a mean fecundability of 0.25 using the formula in (Leridon 1977: 27), [5] (CBS 2014), [6] (Bakker et al. 2009: 33, 55; Levels et al. 2012), [7] (MVWS 2017, 2021)

Table 1: Continued

Parameter	Sample size (by education)	Processing/information	Format
First cohabitation (and cohabitation)	Low: 168, Mid: 469, High: 651	Gumbel distribution (best fit to data, based on AIC), cohort share that ever cohabits 95% based on 1954–1964 GGS cohort and Bellani et al. (2017), education-specific shares calculated with equation systems from the ratios between the educational shares of the 1964–1984 GGS cohort[1] that sum up to the cohort share, share who remain cohabiting after first cohabitation 10%[2]	RNG* compared with CDF* value corresponding to the iteration/month
Cohabitation to marriage	Low: 309, Mid: 798, High: 705	Exponential distribution (best fit to data, based on AIC), cohort share who marry of 58.0% based on CBS reports,[2] 70% share who ever married based on CBS estimates,[3] education-specific shares estimated the same way as first cohabitation, but with 1954–1984 cohort [4]	— 〃 —
Separation	724	Exponential distribution (best fit to data, based on AIC), cohort share who separate of 31.2% based on CBS report,[5] education-specific shares estimated the same way as first cohabitation, but with 1954–1974 cohort [4]	— 〃 —
Re-partnering	250	Gumbel distribution (best fit to data, based on AIC), Re-partnering set at 75%, based on Finnish 1969–1971 birth cohort (76.2%),[6] education-specific shares estimated the same way as first cohabitation, but with 1954–1964 cohort [4]	— 〃 —
Divorce	496	Exponential distribution (best fit to data, based on AIC), cohort share who divorce of 27.6% based on CBS report [7] (separate + marry*divorce ≈ 48%),[2] education-specific shares estimated the same way as first cohabitation, but with 1954–1964 cohort [4]	— 〃 —
Education	Low: 357, Mid: 1,007, High: 1,209	Educational structure from LISS and GGS, duration of enrolment based on expected year of graduation	Educational attainment sampled from distribution

Note: [*] Random Number Generator [0,1] and Cumulative Distribution Function, **[1]** Cohort range expanded to reach sufficient sample sizes to fit distributions, **[2]** (CBS 2019a)**,** **[3]** (Stoeldrajer et al. 2021: 3)**,** [4] Cohort ranges chosen based on the average age at the different union events. The 1974–1984 cohort could not be used because this cohort was too young at the time of the survey to have reliable retrospective data on past union events (especially for highly educated women), [5] (Kooiman, Stoeldrajer, and Harmsen 2021), [6] Ever repartnered/Never repartnered and separated + Ever repartnered). Data is for both sexes combined (Andersson et al. 2022: 2327), [7] (CBS 2022)

4.7 Unintended pregnancies and abortions

Population-representative survey data collected in 2008–2009 suggests that around 18.1% of Dutch women aged 15–70 experienced unintended pregnancies (Bakker et al. 2009: 33, 55). Bayesian model-based estimates of unintended pregnancy in 150 countries, including the Netherlands[21] suggest that in 2015–2019, 14%–24% (99% confidence interval) of pregnancies were unintended (Bearak et al. 2022). On the other hand, the 2003 wave of the Dutch Family and Fertility Survey data suggests that 8% of pregnancies were unintended (Levels et al. 2012). Given that the mean abortion ratio between 2000 and 2020 was 154 abortions per 1,000 live births (Table 1), the 8% estimate seems too low, assuming that most abortions are voluntary decisions by the woman and not due to, for instance, medical emergencies affecting the health of the woman or the foetus. We therefore assumed that 20% of pregnancies were unintended based on the estimates by Bakker et al. (2009) and Bearak et al. (2022).

The Netherlands has high-quality data on abortions at the aggregate level. There is complete coverage of medically assisted abortions performed in the Netherlands for the years 1990–2021, reported annually by the Ministry of Health, Welfare and Sport (MVWS 2017, 2021). From this data we used the abortion ratio, the number of abortions per 1,000 live births. We assumed that abortions were performed on unintended pregnancies, during both spacing and stopping. A probability distribution of the month of pregnancy in which the abortion was performed was also generated based on the abortion data.

4.8 Probability of first cohabitation and transition from cohabitation to marriage

To determine the woman’s age at first cohabitation, for the GGS data the year when she started living with her first partner was used with her year of birth. For LISS, the year when the cohabiting relationship with the respondent’s current partner began was used, provided that they had not married another partner previously. Ideally, we would have needed to know whether the respondent had previously cohabited with another partner, but this information was not available. In GGS the time elapsed between entry into cohabitation and marriage was used as a direct measure of the time between cohabitation and marriage. For LISS the duration was calculated by subtracting the year in which the respondent started living with their current partner and the year they married. In some cases this duration was 0 (direct entry into marriage), which our model essentially

[21] Using Bakker et al.’s (2009) estimate for unintended pregnancies and MVWS data on abortions (Bakker et al. 2009: 33, 55; MVWS 2017, 2021)

captures because we fit an exponential distribution to the data (transition time becomes 1 or a few months instead of 0 as the woman has to enter cohabitation before marriage).

4.9 Probability of separation, divorce, and re-partnering

The probability of separation was produced from the duration of cohabitation until separation. The durations for GGS were simply the year each cohabiting relationship started subtracted from the year each cohabiting relationship ended, provided that the woman did not marry in that relationship. For LISS the principle was the same but the process more complicated[22] because we had to combine the 15 LISS waves into longitudinal partnership trajectories from which the durations of cohabitation could be calculated. This was also the case for extracting divorce and re-partnering data from LISS. To produce the probability of re-partnering, the distribution of the time until re-partnered for the duration between first- and higher-order cohabitations was used. For GGS this was fairly straightforward as the survey is retrospective and has questions on the start and end year of the first four cohabiting relationships of the respondent. As information on the year of marriage was only available for the current partner in GGS, there was no direct measure of the year of marriage for previous marriages. However, we used the information on whether or not the woman married in each of her (up to four) relationships. The sample sizes for all three union events were too small to split into separate distributions by education, but in all three cases the distributions looked similar between educational groups, so we assume that this did not bias our results.

4.10 Enrolment in education

Enrolment in education was based on the reported highest attained level of education in GGS and LISS of women above age 24, to ensure they had time to achieve the International Standard Classification of Education (ISCED) level 5. The expected ages at completion of education of each of the educational categories, which were:

1. Low: ISCED 1–2 (VMBO), age 18 (graduation at 16, but schooling compulsory until age 18)
2. Medium: ISCED 3–4 (MBO), age 20
3. High: ISCED 5–8 (WO/Master), age 22

[22] See the code and data description on GitHub (https://github.com/rofa-g/LIFERT)

As pregnancy and childbirth are rare during enrolment in education, women were assumed to have no conceptions while enrolled.

4.11 Validating the simulation model

To verify that the parameters and distributions we estimated from the various data sources we used resulted in realistic outcomes, we compared the output of our model with reference data from the Human Fertility Database (HFD) and Statistics Netherlands (CBS).

In Table A-1 the simulated cohort aggregates are compared with the input aggregates, demographic data from the Human Fertility Database, or estimates based on information from various reports by Statistics Netherlands. See the table notes for how fertility within coresidential cohort fertility was calculated from total cohort fertility. The main outcomes of interest in the validation were the fertility gap, the mean ages at birth, and the share of women who had 0, 1, 2, 3, or 4 births. Important to note is that the reference data for these outcomes of interest were not used as model inputs in the simulation. Our simulation produced outputs that were close to the reference data but our estimated fertility gap was slightly smaller, and we overestimated the share of women who ended up childless and underestimated the share of women with one child. Given that our model includes neither multiple births nor assisted reproductive technology, the model would be expected to overestimate the fertility gap somewhat. The probability of a multiple birth is around 1% for natural pregnancies (van Eekelen et al. 2020), and assisted reproductive technologies are expected to increase the number of births by up to 2% (Passet-Wittig and Bujard 2021: 432). The underestimation of the fertility gap in our model likely relates to uncertainty in three parts of the model: the intended family size, the contraceptive behaviour, and the timing of union events. First, as we discussed in the data section, fertility intentions are prone to downward adjustment over the life course, especially long-term fertility intentions. Second, we are unlikely to perfectly capture contraceptive behaviour because it is complex and relies entirely on self-reported data on contraceptive use and unintended pregnancies. Third, small sample sizes for transition between union events led to imperfectly fitting distributions, and in our case earlier union events than in the raw data.

As for the overestimation of childlessness, our model only produces births within coresidential unions, but the reference estimates are for all births to mothers in the cohort. The age distribution of births to mothers not in a coresidential union (CBS 2023a) suggests that the births our model is missing are likely first births.[23] This would explain

[23] Non-coresidential births concentrated in the youngest and oldest reproductive ages. A birth outside of coresidence is likely an indication of a strong desire to enter motherhood for women at older reproductive ages:

why we overestimate the share of women who end up childless and underestimate the share of women with one child. The notes to Table A-1 discuss this in more detail.

Table A-2 shows the simulated aggregates by educational category. The main takeaway here is that we reproduce the educational gradient in completed cohort fertility reasonably well when comparing our results with population register data on Dutch women born during 1966–1970 (Nisén et al. 2021: 270). This also gives us confidence in our model inputs and the way we model education and unions in our simulation.[24] What can also be seen in the summary is the interaction between timing of first cohabitation (and conception) and physiological constraints (decline in fecundity, increased risk of miscarriage). The share of women who were childless or reached higher parities increased or decreased respectively with education, and the share of miscarriages per live birth increased.

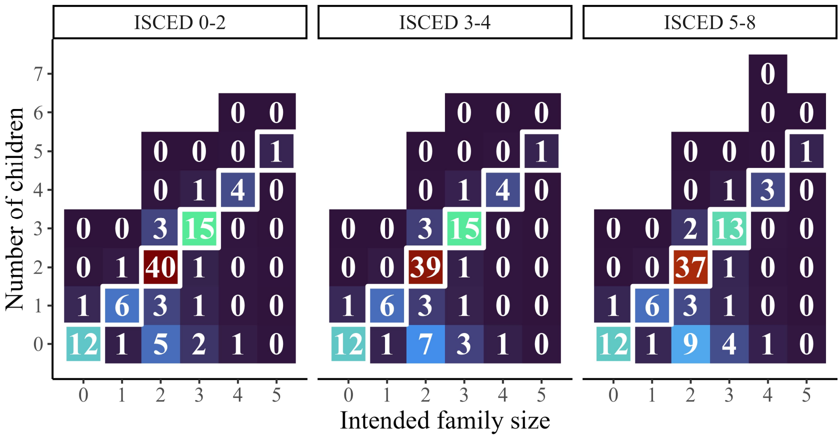
5. Results

In Figure 3 we can see that the majority of women achieved their intended family size, represented by the diagonal line with white borders. This share of women declines from around 78% of women with a low level of education to 72% of women with a high level of education. The fertility gap was mainly a result of women intending to have 2 or 3 children but ending up childless or with 1 child. There was also some (4%–6% of women) overachievement of intended family size, mainly women who intended to have 2 children but ended up having 3 children instead.

women under 20 years of age are unlikely to have had a birth previous to the registered birth outside of coresidence.

[24] In case the reader wonders why highly educated women are shown to have a higher percentage of separation than low-educated women in Table A-2, despite the fact that highly educated women have a lower probability of separating, it is because the share of highly educated women entering marriage is considerably lower (52% vs. 64%). Therefore more highly educated women than low-educated women are subject to the probability of separation, resulting in more separations per cohabitation (all unions start with cohabitation).

Figure 3: Distribution (%) of the fertility gap by educational attainment (low, medium, high)



Note: Most women realised their fertility intentions (diagonal line); underachievement (below line) was much more common than overachievement (above line). The fertility gap increased somewhat with education (ICSED 0–2: low, ISCED 3–4: medium, ISCED 5–8: high). The numbers in each cell represent percentages of the total rounded to integers.

We measured the importance of the different components in our model in two steps. First, we calculated how much changes in the individual parameters contributed to the fertility gap observed in our simulated cohort (Table 2). This table can be interpreted as the absolute contribution each parameter change made in our sample cohort. To assess the importance of change in the physiological parameters we fixed fecundability and intrauterine mortality at a high and low level respectively and found that this reduced the gap by around 0.11 (from 0.34 to 0.24) or 30.8%. This reduction is almost entirely attributable to the decline in fecundability by age, being the determinant of natural conception and larger in magnitude on average. Intrauterine mortality, on the other hand, determined the transition from conception to live birth. In our model intrauterine mortality only occurred in cases where the conception was successful and there was not an induced abortion.

The share of cohabitations that ended in separation and those that resulted in marriage made the greatest absolute contributions to the fertility gap. Fixing the share of cohabitations that ended in separation at 0% (31.45 percentage point decrease) and the share of cohabitations that resulted in marriage at 100% (42.51 percentage point increase) reduced the fertility gap by 0.18 (52.6%) and 0.16 (47.3%) respectively. This suggests that separation constitutes an important disruption to fertility, and that marriage (commitment to the union) is associated with higher union stability (lower probability of divorce than separation), increasing the union duration and probability that a woman reaches her intended family size. The contribution of marriage was smaller because marriage occurred at older ages than separation (affecting fewer potential conceptions) and subjected all women,[25] including the 10% of women who would otherwise have stayed cohabited for the rest of their reproductive lives, to the probability of divorce.[26] Setting the share of all women who re-partner to 100% (26.59 percentage point increase) reduced the fertility gap by 0.13 (37.4%), which shows that re-partnering is an important offset to union dissolution but does not completely compensate for fertility lost due to separation and divorce.

Table 2: Absolute (complete) contributions to the fertility gap by the change in each parameter for the simulated 1974–1984 Dutch cohort of women

Parameter	Adjustment	Change in parameter	Contribution to fertility gap	Contribution in per cent
Fecundability	No decline until sterility	No 12.5-year linear decline	–0.0904	–26.40
Intrauterine mortality	Fixed at the level of 20-year-old	No cubic increase	–0.0151	–4.42
Age at first cohabitation	Set to age 15	–8.66 years	–0.0932	–27.20
Transition time from cohabitation to marriage	Set to 1 month	–35 months (avg.)	0.0276	8.07
Time spent finding new partner	Set to 1 month	–29 months (avg.)	–0.0362	–10.60
Share of cohabitations ending in separation	Set to 0%	–31.45 percentage points	–0.1800	–52.60
Share of marriages ending in divorce	Set to 0%	–25.59 percentage points	–0.0359	–10.50
Share who marry	Set to 100%	+42.51 percentage points	–0.1620	–47.30
Share who re-partner	Set to 100%	+26.59 percentage points	–0.1280	–37.40
Share who ever cohabit	Set to 100%	+4.97 percentage points	–0.0379	–11.10

Note: The parameter adjustments were chosen to measure the entire contribution each parameter made. So, for instance, how much would the observed fertility gap in our sample cohort, where around 31% of cohabiting couples separated, be reduced in the hypothetical case where no separations occur? It would be reduced by 0.18 children (52.6%).

[25] In the case where separation is set at 0%, only the 58% of women who transition to marriage are subject to the probability of divorce, whereas in the case where marriage is set at 100%, all women are subject to the probability of divorce because all women transition to marriage.

[26] The probability check for marriage occurs before the probability check for separation and whether the woman remains cohabited for the rest of her reproductive life in the simulation model. See code scripts for details.

Setting the age at first cohabitation to 15 (8.66-year decrease) reduced the fertility gap by around 0.09 (27.2%). This postponement of first entry into cohabitation increases the fertility gap non-linearly because fecundability declines and intrauterine mortality increases at older reproductive ages (Figures A-3 and A-4). Union events, on the other hand, scale linearly (in our model), as the probability is uniform across the woman's life course. Fixing the share of women who ever cohabit at 100% (4.97 percentage point increase) reduced the fertility gap by 0.04 (11.1%), making it the strongest contributor to the fertility gap among the union events in relative terms (see Figure A-5 for a comparison of the relative contributions of the union-related parameters).

Reducing the transition times to marriage and re-partnering to 1 month (35-month and 29-month decrease) increased (0.03, 8.1%) and reduced (0.04, 10.6%) the gap slightly. The increase in the gap due to shorter transition times to marriage occurs because the shorter transition time reduces the average duration of non-marital coresidential unions. For re-partnering, on the other hand, the reduction shortens the time spent outside of a coresidential union. This results in more time to conceive a child (more children born), and hence a negative contribution to the fertility gap. Fixing the probability of divorce at 0% (25.59 percentage point decrease) reduced the gap by as little as 0.04 (10.5%), because only around 58% of unions resulted in marriage and the mean age at first divorce was high at 35.8, making it a late disruption to childbearing.

Next, we examined the educational difference in the fertility gap by measuring the contribution to this difference of education-related parameters (Table 3). We did this by using a simulation of only low-educated women as the baseline, and then individually adjusting each education-specific parameter to the value of highly educated women, while keeping all the other education-related parameters at the level of a low-educated woman.[27] The mean difference in the gap was 0.17 (highly educated women had 0.17 fewer children than women with a low level of education). The educational difference was mostly explained by highly educated women's later entry into first cohabitation, and the lower share of highly educated women who ever enter into a coresidential union. The lower probabilities of marriage, separation, and divorce among highly educated women and longer transition time to marriage compared to low-educated women almost cancelled each other out.

The slightly lower probability of re-partnering and higher age at graduation for highly educated women made no contribution to the fertility gap because of the small

[27] So, in the case of the age at first cohabitation, the baseline was the value of low-educated women for all the education-specific parameters. Then the probability distribution for entering the first coresidential union was set to that of a highly educated woman, while all other education-specific parameters were kept at the values of a low-educated woman. The resulting difference in the fertility gap (low-educated women compared to high-educated women) between the two simulations is the contribution to the difference in the fertility gap reported in Table 3. The percentage contribution is the contribution as a percentage of the total difference of 0.17.

difference in re-partnering and graduation occurring very early in the reproductive life, even for women who entered tertiary education.

Table 3: Composition of the educational difference in the fertility gap

Parameter	High education (ISCED 5–7)	Low education (ISCED 0–2)	Individual contribution to difference in the fertility gap	Individual contribution in per cent
Fertility gap	**0.41**	**0.24**	**0.17**	**100.00**
Age at first cohabitation	25.43	22.33	0.12	67.00
Share who ever cohabit (%)	93.91	99.85	0.07	42.59
Transition time to marriage (years)	4.32	5.09	–0.01	–7.09
Share of cohabitations resulting in marriage (%)	51.98	64.25	0.07	40.96
Share of cohabitations resulting in separation (%)	25.17	30.40	–0.04	–23.50
Share of marriages resulting in divorce (%)	24.77	30.76	–0.01	–6.63
Share of union dissolutions resulting in re-partnering (%)	72.55	74.34	0.00	0.80
Age at graduation (enrolled until age)	22	18	0.00	2.20

Note: The sum of the individual contributions to the difference in the fertility gap add up to over 0.17 (100%) because there are interactions between the parameters. When cumulatively summing up the parameter contributions they add up to just over 100%, with the inaccuracy resulting from variation between simulation runs. Calculation of this cumulative contribution can be found in the script on GitHub (https://github.com/rofa-g/LIFERT)

To get an idea of how the fertility gap might change for a younger cohort, we adjusted the share of all women who enter the different union state by 5 percentage points each, to reflect a possible modest change over the short term. This was also done to compare the contributions of each type of union event, which is illustrated in Figure A-5. We included the educational structure of women born during 1988–1997 to see how the educational composition would change the fertility gap for this cohort according to our model. Lastly, we adjusted the mean age at entry into first coresidential union by 1, 2, 3, 4, and 5 years to show how postponement of entry into a first coresidential union progressively increases the fertility gap (also illustrated in Figure A-3). The results are shown in Table 4.

The contribution of the change in educational structure was small at 0.02 (5.2%). The educational structure in itself is therefore unlikely to be an important driver of the fertility gap for the two cohorts we compared. This is partly because the share of women with a low level of education was small (14.3% for 1974–1984 cohort, 8.3% for 1988–

1997 cohort), and partly because highly educated women in our sample had more stable relationships that compensated for their lower entry into cohabitation and marriage.

An increase of 5 percentage points in separation and a decrease of 5 percentage points in the share who marry and re-partner produced similar contributions of around 0.02–0.03 (6.9%–8.2%) to the fertility gap. An increase in the share of women who divorce[28] by 5 percentage points contributed less at 0.01 (4.2%), for previously mentioned reasons. The two adjustments that increased the fertility gap the most were increases in the share of women who never entered a coresidential union[29] and continued postponement of entry into first cohabitation.[30]

[28] For a visualisation of how differently the number of separations and divorces affected the fertility gap of women in our simulation, see Figures A-6 and A-7 in the Appendix

[29] ESS and EVS data suggest that more Dutch women than men remained single throughout their lives, and that tertiary-educated women in the EU were more likely to never partner compared to women with a lower secondary (or below) or upper secondary education (Bellani, Esping-Andersen, and Nedoluzhko 2017). As the expansion in higher education has been greater for women than for men (Eurostat 2023) and there has been a persistent positive educational gradient in childlessness in the Netherlands (CBS 2017; Miettinen et al. 2015), if we assume assortative mating we expect that the share of lifelong single women will increase. It is possible that these patterns and the educational gradient in lifelong singlehood will change in the Netherlands as they have in the Nordic countries (Jalovaara et al. 2019), possibly due to increased gender equality (Bellani, Esping-Andersen, and Nedoluzhko 2017). The Netherlands, with its one-and-a-half income earner norm (CBS 2013, 2019b, 2023d) is, however, quite different from the Nordic countries, having the EU's highest rates of part-time employment among women (Eurostat 2024). This implies that most women in Dutch heterosexual couples sacrifice career prospects for motherhood (CBS 2023d), which may also be reflected in whether and when they enter a coresidential union.

[30] Based on the author's calculation of the shares of 18 to 29-year-olds who had had their first cohabitation, there was an average decrease of around 18% between 2013 and 2023. There was a greater concentration of first cohabitation towards the older ages in 2023 (CBS 2024b). The age at which young Dutch adults moved out from the parental home also gradually increased between 2012 to 2022, from age 22.0 to 23.0 for women and 23.5 to 24.4 for men (CBS 2024a).

Table 4: Contribution to the fertility gap of possible future changes in individual parameters

Parameter	Adjustment	Contribution to fertility gap	Contribution in percent
Share of highly educated	25–34-year-olds in 2022*	0.02	5.18
Share who separate	Increase by 5 percentage points	0.02	6.91
Share who divorce	Increase by 5 percentage points	0.01	4.15
Share who marry	Decrease by 5 percentage points	0.03	7.53
Share who re-partner	Decrease by 5 percentage points	0.03	8.23
Share that ever cohabit	Decrease by 5 percentage points	0.08	22.24
Age at first cohabitation	Increase mean by 1 year	0.04	11.36
Age at first cohabitation	Increase mean by 2 years	0.08	22.79
Age at first cohabitation	Increase mean by 3 years	0.12	35.41
Age at first cohabitation	Increase mean by 4 years	0.17	50.14
Age at first cohabitation	Increase mean by 5 years	0.23	65.91

Note: *Women born during 1988–1997 vs. 1974–1984
ISCED 0–2: 8.3% vs. 14.3%,
ISCED 3–4: 30.8% vs. 38.8%,
ISCED 5–8: 60.9% vs. 46.8%

6. Discussion

Our microsimulation model aimed to measure which the most important contributors to the gap between the intended family size and completed cohort fertility of Dutch women born during 1974–1984 were. Our counterfactual analysis showed that separation in particular has become an important disruption to fertility. The mean age at first separation was 28 years, close to the mean age at first birth of 29 years, and the share of cohabitations ending in separation was high at 32%. Separation therefore disrupted first births and the transition to parenthood in particular. Empirical studies in other European countries have reached similar conclusions about the relationship between separation and fertility (Jalovaara and Fasang 2017; Jalovaara and Kulu 2018; Thomson, Winkler-Dworak, and Beaujouan 2019).

Divorce, on the other hand, made a smaller contribution at the cohort level because marriages lasted much longer on average (around 10 years, versus 4 years for cohabitations), only around 58% of unions resulted in marriage, and divorce occurred late in the reproductive life course (mean age at divorce was 35.8 years). Because a large share of all births occurred before divorce, and because of age-related physiological constraints on fecundity, union disruptions at these older reproductive ages contributed less to the fertility gap. The differences between separation and divorce also reflect the broader change in union dynamics towards less stable unions, observed over the past few decades in Europe (Kalmijn and Leopold 2021). We found that re-partnering was an important offset to union dissolution, but it did completely compensate for fertility lost due to union dissolution. This is in line with previous research on the contribution of re-partnering to fertility outcomes (Andersson et al. 2022; Ivanova, Kalmijn, and Uunk 2014; Thomson et al. 2012; Vanassche et al. 2015; Winkler-Dworak et al. 2017).

Two other union-related factors we were able to model that are less often studied in the fertility context were age at first cohabitation, and never entering a coresidential union (lifelong singlehood). No postponement of entry into first cohabitation (by setting the age at first cohabitation to 15) considerably reduced the fertility gap. Assuming that the age at first entry into a coresidential union keeps increasing (CBS 2024b), the importance of this postponement to completed fertility and the fertility gap will increase non-linearly, given that physiological constraints on fertility are concentrated at older reproductive ages (Figures A-3 and A-4). The share of women who never entered a coresidential union made an even greater contribution to the fertility gap than postponement, as fewer women ever entering a coresidential union reduced the number of potential mothers in our simulation. For our sample cohort, only an estimated 5% of women never cohabited. There is, however, evidence that singlehood is becoming increasingly common, and that there is a positive educational gradient in young singlehood that is somewhat stronger for women than for men (van den Berg 2023; Esteve et al. 2020). This suggests that the inability to find a partner to cohabit with may play an increasingly important role in determining fertility outcomes in the near future, with the caveat that births outside of coresidential unions (which we were unable to model) may also increase, as they have done in the Netherlands until recently (CBS 2023a).

For education we observed a sizeable (0.2 child) difference in the fertility gap between women with a high and low education. Most of this difference was explained by the fact that highly educated women were considerably less likely to ever enter into a coresidential union, and did so on average three years later than women with a low level of education. The finding that highly educated Dutch women partner less and later likely relates to their greater investment in and emphasis on education and career, as well as greater difficulty finding a partner to form a family with. Our results therefore tentatively[31] predict that in an increasingly highly educated Dutch (female) population, fewer women will on average enter cohabitation and marriage, but their relationships will on average be more stable. Interestingly, civil partnerships have gradually become more common since the late 1990s and have the same legal (if not symbolic) weight as

[31] Whether the educational gradient in lifelong singlehood will change for younger cohorts of Dutch women is still unclear, as these women are currently in the early stages of their union formation trajectories. However, assuming continued assortative mating, a persistent (increasing) gap between the share of highly educated women and highly educated men and a persistent positive educational gradient in childlessness in the Netherlands would support our prediction.

marriages in the Netherlands (CBS 2024c), which adds another layer of complexity to the analysis of union dynamics in the Dutch context.[32]

Our simulations of possible future scenarios yielded very similar results to our analysis of the determinants of the gap. We find that the increasing share of highly educated Dutch is unlikely to be a strong driver of fertility decline in the near future, as the lower rate of and later entry into unions among highly educated Dutch women are partially compensated for by more stable unions. However, further studies into the difficulty balancing early career and family, among other topics, are required for a more detailed understanding of the relationship between education and childbearing (Adda, Dustmann, and Stevens 2017; Connolly and Gregory 2009; Doepke et al. 2022; Gjerdingen et al. 2001; Verweij et al. 2021). Future Dutch cohorts experiencing anything resembling the increase in lifelong singlehood seen in East Asian countries like Japan (Kottmann and Dales 2023) could be a concern, as the fertility gap would increase considerably for these cohorts. It may therefore be worthwhile paying more attention to how singlehood is developing and investigating why individuals end up remaining single in the Netherlands (Apostolou et al. 2021; Apostolou and Tsangari 2022). If the mean age at first birth continues to increase as it has over the past decades, physiological constraints on fecundity will become increasingly important in determining the size of the fertility gap. It would therefore be wise to increase awareness among individuals and couples about fertility and reproductive health in relation to age (Habbema et al. 2015; Martins et al. 2024).

7. Limitations

While our microsimulation advances existing models by bridging the gap between more behaviour-focused and physiology-focused models, it is still missing several important parts of the fertility process. These include personality traits, career paths, and assisted reproductive technologies, to name a few. Data, however, becomes scarce when trying to combine a large set of such parameters, and including all of them in one model requires information on the numerous mechanisms that connect them, which inevitably increases the number of assumptions that have to be made and the complexity of the model. Our model is also not able to handle reverse causality from reproductive behaviour to partnering outcomes. It is therefore not well-suited for causal analysis. Just like any other model, ours is a simplification of reality, and we can only draw conclusions based on the set of parameters that we include in our model at the level of detail that we model them on.

[32] Neither the GGS I data nor the LISS panel data that we used had response options for registered partnerships, but this response option is included in the questionnaire used for the Dutch GGS II data, released in 2024.

Another limitation of our study is the small sample sizes for some of our model distributions. This will at least partly be addressed once the most recent GGS data for the Netherlands is published, given that the GGS data we used in this study is already 20 years old. The data-related issues might also be resolved by having access to microdata from Statistics Netherlands' population registers (CBS 2024d). There is, however, value in finding solutions that work without individual-level population register data, as only a handful of countries keep such registers, whereas representative data that is comparable across a wide range of countries can be found in international surveys like GGS. Part of the idea behind our model is, after all, to make it applicable to various contexts and research problems related to fertility.

8. Conclusion

We have demonstrated that the microsimulation approach we have developed can serve as a useful tool for better understanding the fertility process and the mechanisms that underlie fertility outcomes. We measured the contributions to the fertility gap of education, different union events, and physiological constraints observed in our sample cohort. We were also able to model how education itself and the educational gradient in union formation and dissolution interact with physiological constraints on fertility to produce part of the fertility gap. This allowed us to assess which factors likely contributed the most to the fertility gap, and which of them are likely to be the most important in the near future.

We were not able to fully explain the gap between intended family size and completed cohort fertility in the Netherlands with our microsimulation model, despite it being one of the most ambitious attempts at simulating the reproductive life courses of women (couples) so far. Factors like career trajectories, economic uncertainty, childbirth outside coresidential unions, and assisted reproductive technologies still remain unexplored. How well our model can be extended to these cases and other contexts remains to be seen. We have nonetheless taken a promising step towards an alternative approach to modelling the fertility process, as well as quantifying the determinants of fertility outcomes.

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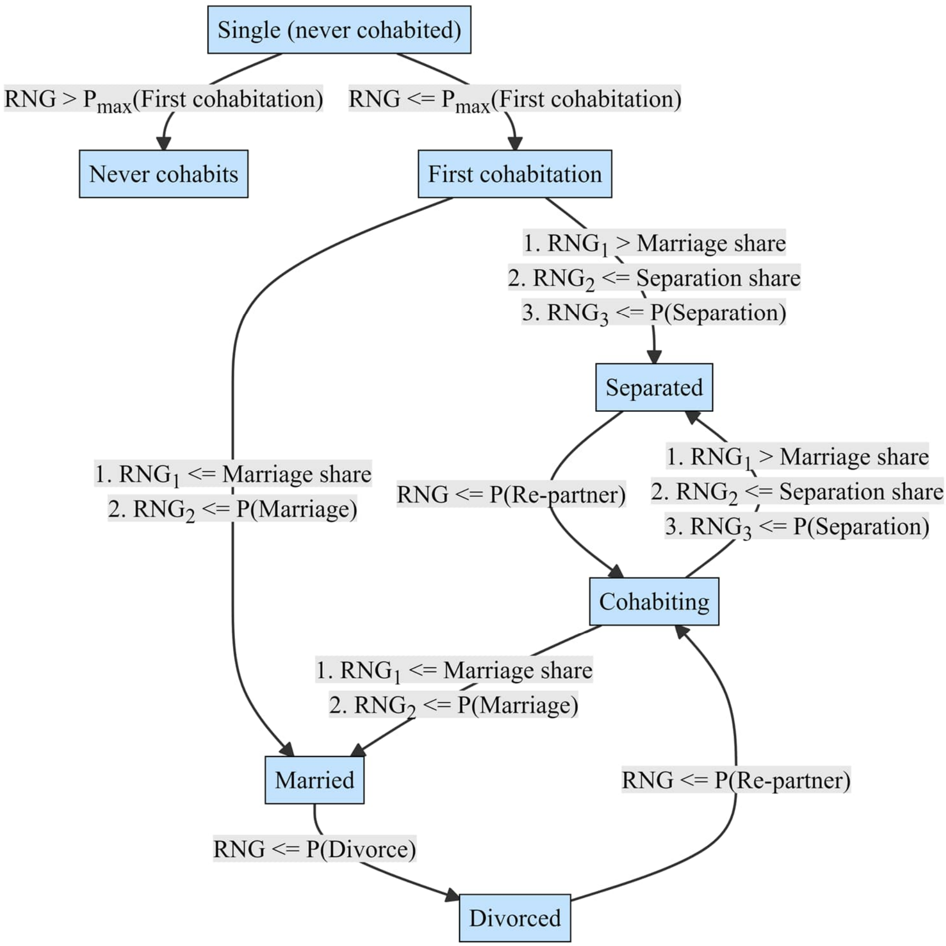
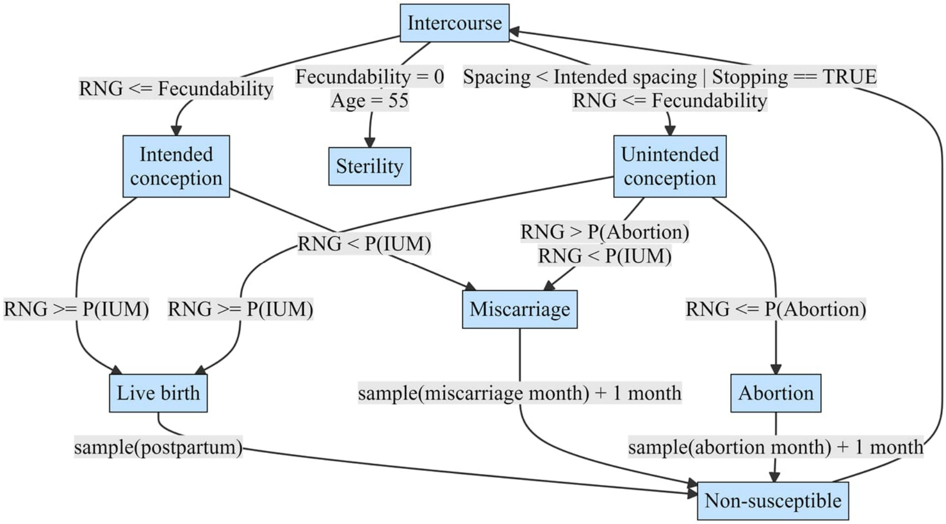
Appendix

Figure A-1: Union formation simulation



Note: RNG refers to a (pseudo) randomly generated number between 0 and 1, which is compared to a cumulative distribution function. The month in which the randomly generated number meets the specified transition condition(s), the event occurs. If the transition conditions are not met, the woman remains in her current state. P_{max} refers to the maximum value of the cumulative distribution function.

Figure A-2: Simulation of the reproductive process (while cohabiting or married)



Note: RNG refers to a (pseudo) randomly generated number between 0 and 1. IUM refers to intrauterine mortality. Stopping is when the woman has reached her intended family size, spacing is the period during which the woman is not yet trying to get pregnant. Sterility is an absorbing state, and ends the simulation. Abortion here refers to (medically) induced abortion. The arrows from live birth, miscarriage, and abortion to non-susceptible denote the time spent in the state of non-susceptibility. 'sample' refers to random sampling from the corresponding distributions.

Table A-1: Simulation results versus reference data (100k sample)

Indicator	Demographic data	Simulation results (1974–1984 cohort)
Mean age at first cohabitation (GGS, LISS)	24.5	23.748
Mean age at first marriage (CBS, 2004–2014)[1]	29.7	28.644
Mean age at first separation, no previous divorce (GGS, LISS)	28.5	27.786
Mean age at first divorce (GGS, LISS)	37.6	35.768
Mean age at first re-partnering		32.362
Percentage ever cohabited (GGS, estimate)	95	95.133
Percentage ever married (CBS, estimate)[2]	70	72.138
Percentage cohabited and never separated or married (CBS, estimate)[3]	10	9.518
Percentage marriage (cohabitation to marriage; CBS, estimate)[3]	58	57.494
Percentage separation (CBS, estimate)[4]	32	31.448
Percentage divorce (CBS, estimate)[5]	27.6	25.587
Percent re-partnering (Finnish register data[6] estimate)	75	73.409
Mean age at first birth (HFD, 1979 cohort)[7]	29.2	28.945
Mean age second birth (HFD, 1979 cohort)[7]	31.6	31.462
Mean age third birth (HFD, 1979 cohort)[7]	33.1	33.357
Mean age fourth birth (HFD, 1979 cohort)[7]	34.5	34.840
Completed cohort fertility within coresidential unions (total births in parenthesis) (HFD, 1979 cohort)[7]	1.66 (1.80)	1.682
Fertility gap within coresidential unions (total births in parenthesis)	0.364 (0.227)	0.342
0 children (HFD, 1969 cohort, %)	17.6	25.333
1 child (HFD, 1969 cohort, %)	18.5	11.448
2 children (HFD, 1969 cohort, %)	42.7	40.135
3 children (HFD, 1969 cohort, %)	15.6	17.216
4+ children (HFD, 1969 cohort, %)	5.6	5.868
Miscarriages per live birth		0.180
Percentage unintended pregnancies[8]	20	20.104
Abortion ratio 2000–2020[9] (abortions per 1,000 live births)	154	155.422

Note: (see some details in the data description table, Table 1):
First, a general note about the simulated mean ages at union events being younger than in the reference (raw) data. This is because parametric distribution functions were fitted to the data, and the data did not fit any distribution perfectly. Second, the severely overestimated share of childless and underestimated share of women with one child compared to the reference data are because our model is missing 7.8 percentage points (10–2.2 percentage points) of the births that occur outside coresidential unions. When assuming that these missing births were first births (argument in the model validation section), the share of childless women produced by our model was 18.8% and the share of women with 1 child was 17.9%, which is close to the reference. The overestimation of childlessness that remains could be because the reference estimate is for the 1969 birth cohort, which may have had lower childlessness than the 1974–1984 birth cohort.

[1] Mean age at first marriage estimated by calculating the difference in the mean age at first marriage for 2022 (36.4–32.8 = 3.6), subtracting this difference from the mean ages at marriage 2004–2014, and taking the mean of those means. 2004–2014 was chosen to roughly cover the age at first marriage range (ages 30–40) for the simulated 1974–1984 cohort.

[2] (Stoeldrajer et al. 2021: 3.2.5)

[3] (CBS 2019a)

[4] (Kooiman, Stoeldrajer, and Harmsen 2021)

[5] (CBS 2022)

[6] Ever repartnered / (Never repartnered and separated + Ever repartnered). Data is for both sexes combined (Andersson et al. 2022: 2327)

[7] The mean ages at birth and completed cohort fertility are approximations based on means for women aged 40, as the 1979 cohort has not yet completed its fertility. The approximation is the trend in the difference between means for women who had completed their fertility and women aged 40 for the 1959–1969 birth cohorts.

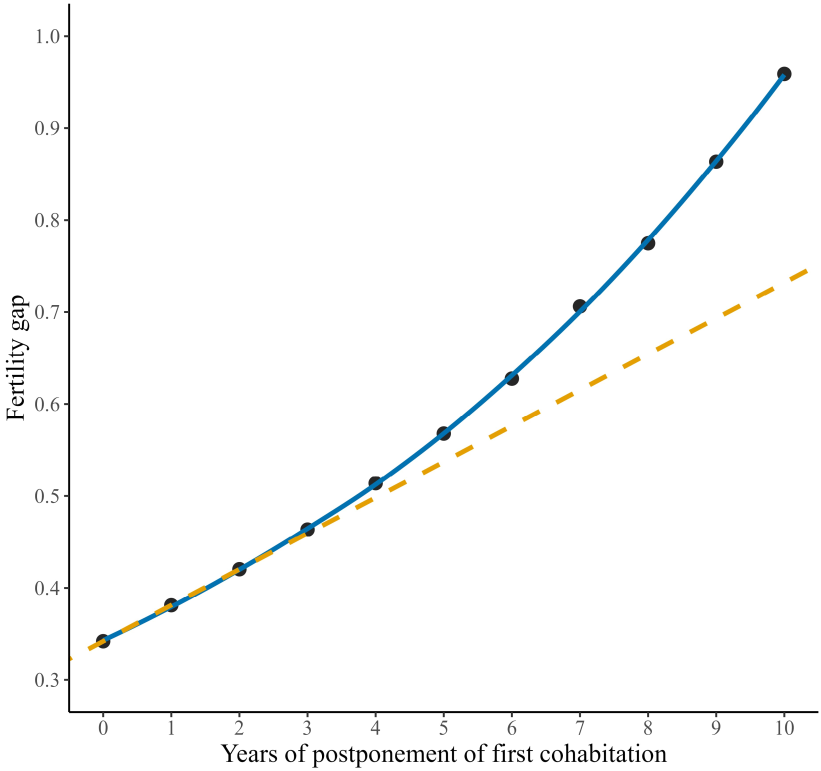
[8] (Bakker et al. 2009:33, 55; Bearak et al. 2022; Levels et al. 2012)

[9] (MVWS 2017, 2021)

Table A-2: Simulated averages by education (100k sample)

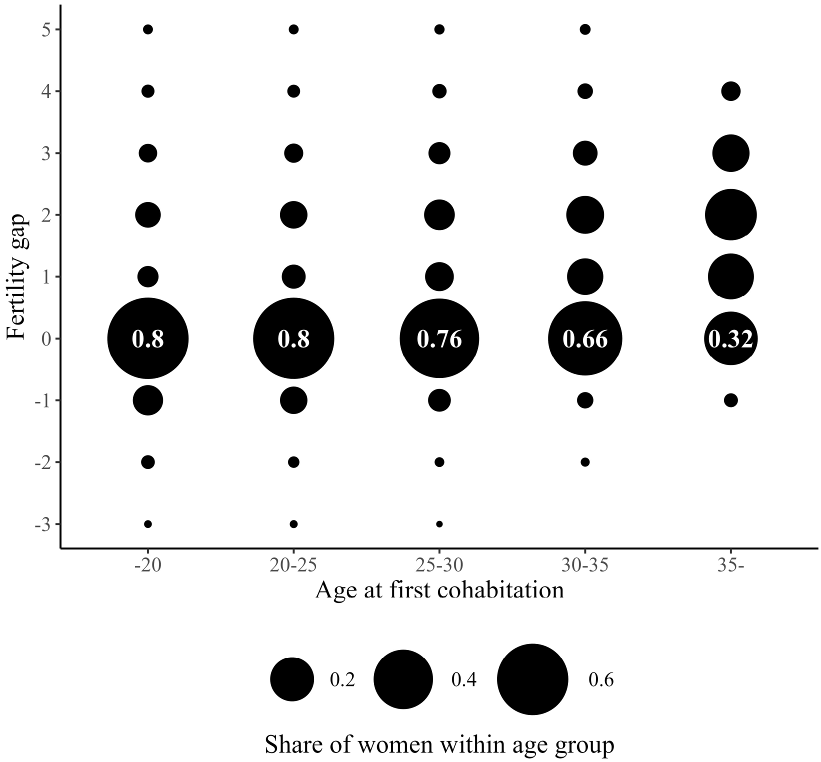
Educational level	ISCED 0–2	ISCED 3–4	ISCED 5–8
Mean age at first cohabitation	22.320	23.016	24.813
Mean age at first marriage	26.675	27.858	30.130
Mean age at first separation	26.139	27.010	28.730
Mean age at first divorce	34.121	35.253	37.100
Mean age at first re-partnering	31.307	31.929	33.076
Percentage ever cohabited	99.836	94.764	94.040
Percentage ever married	84.260	74.940	66.200
Percentage marriage (cohabitation-marriage)	64.488	61.501	51.890
Percentage separation	30.063	28.542	34.294
Percentage divorce	30.502	25.280	23.867
Percentage re-partnering	74.230	74.071	72.606
Mean age at first birth	27.532	28.247	30.008
Mean age at second birth	30.067	30.822	32.490
Mean age at third birth	32.136	32.836	34.261
Mean age at fourth birth	33.742	34.430	35.599
Completed Cohort Fertility	1.787	1.725	1.616
Fertility gap	0.237	0.300	0.409
Percentage 0 children	21.036	24.351	27.429
Percentage 1 child	11.808	10.732	11.936
Percentage 2 children	42.345	40.677	39.026
Percentage 3 children	18.606	18.007	16.144
Percentage 4+ children	6.204	6.233	5.464
Miscarriages per live birth	0.165	0.178	0.186
Percentage unintended pregnancies	20.563	19.916	20.121
Abortion ratio (abortions per 1,000 live births)	157.775	152.895	156.890

Figure A-3: Increase in the fertility gap by years of postponement of first cohabitation (base model)



Note: The blue solid line is the local polynomial regression fitting line on all the data points, the orange dashed line is the linear regression line fitted to the three first observations (purely for illustrating the non-linear increase in the fertility gap with years of postponement of first cohabitation).

Figure A-4: Fertility gap by age at first cohabitation



Note: While the size of the bubbles on the zero line (women who achieved their intended family size) decline gradually until the 25–30 age group, the decline is particularly large between age groups 30–35 and 35–. The same applies for the share of women with a fertility gap.

Figure A-5: Relative contributions of each union-related parameter

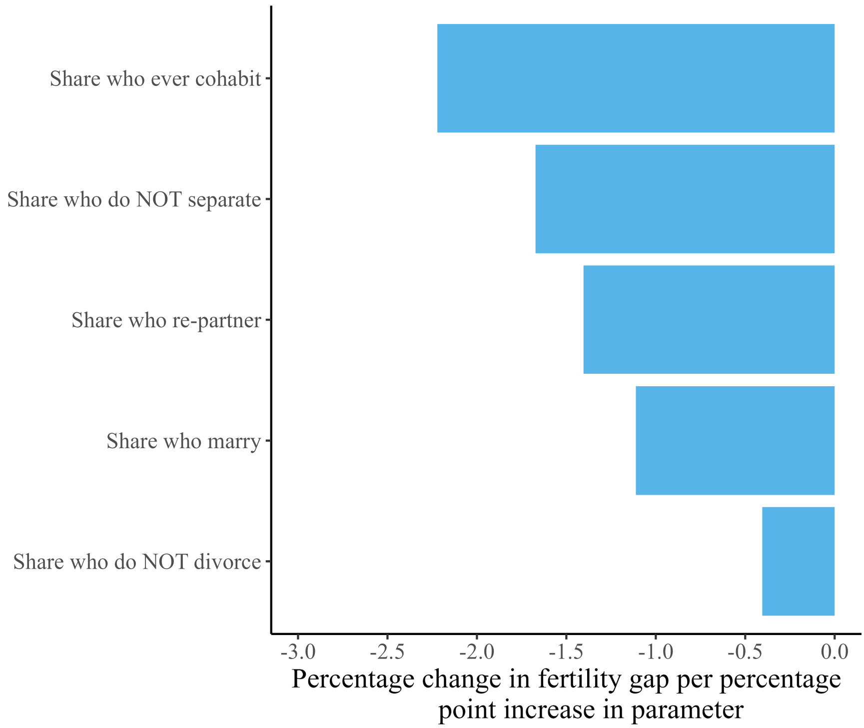
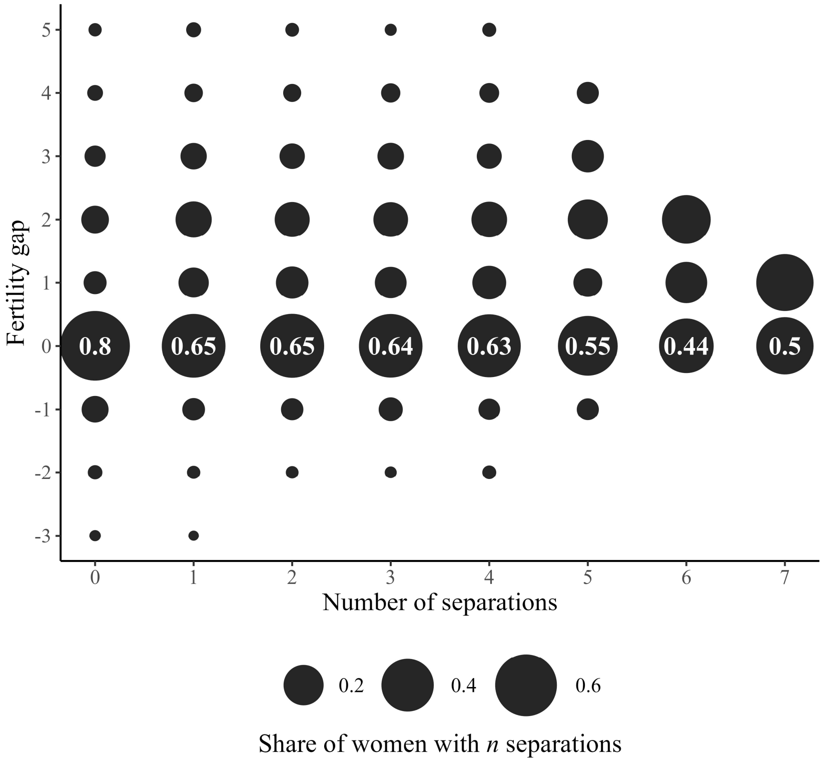
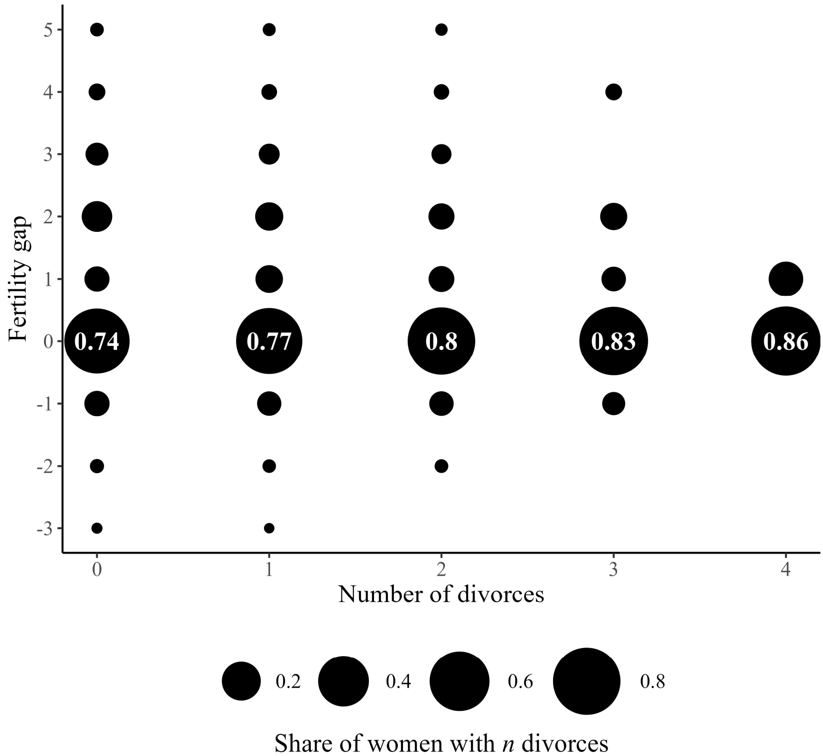


Figure A-6: Distribution of the fertility gap by number of separations



Note: We can see that the first separation reduces the relative share of women who achieve their intended family size, but this share declines gradually until the 5th separation. The increase observed at the transition to the 6th and 7th separations are outliers who spend a very long time in the reproductive simulation due to early entry into first cohabitation and high ages at sterility.

Figure A-7: Distribution of the fertility gap by number of divorces



Note: The increase in the relative share of women who achieve their intended family size with the number of divorces they had relates to the fact that marriages on average lasted for a long period of time, so the women who had one or more divorces likely spent more time in the reproductive part of the simulation because of earlier entry into first cohabitation and higher ages at sterility.