Does Parental Education Affect Fertility? Evidence from Pre-Demographic Transition Prussia[2]

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Abstract

A growing literature places the Industrial Revolution and the Demographic Transition in a unified framework. Whereas there is evidence on the effect of employment opportunities for women, relative wages, and the child quantity-quality trade-off on fertility limitation, the role of parental education has received little attention. We combine Prussian county-data from three different censuses to estimate the relationship between women's education and their fertility on the eve of the demographic transition. Despite controlling for several fertility demand and fertility supply factors, we find a *residual* negative effect of women's education on fertility. Instrumental variables estimates, using exogenous variation in women's education driven by differences in landownership inequality, suggest that the effect of women's education on fertility is causal.

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1 Introduction

The Demographic Transition, together with the Industrial Revolution, is one of the most important events in modern history as it marks the transition from Malthusian stagnation to modern economic growth. As recently formalized by unified growth theories (Galor and Weil, 1999, 2000), the demographic transition with the reduction in fertility rates and population growth allowed the economies to experience an unprecedented growth of income per capita.

There is a large theoretical and empirical literature which addresses the causes of fertility restraint and much attention has been devoted to the impact of employment opportunities for women, the effect of the female relative wage, and the child quantity-quality trade-off (Crafts, 1989; Galloway, Hammel, and Lee, 1994; Galloway, Lee, and Hammel, 1998; Brown and Guinnane, 2002; Dribe, 2009; Becker, Cinnirella, and Woessmann, 2010). Yet, the role of parental education, and in particular of women's education, has received little attention. In demography and development economics there is abundant evidence about the negative association between mothers' education and fertility, so that Cochrane (1979) argued that it is "one of the most clear-cut correlations" in the social sciences.[1] However, historical evidence about this relationship and its causal effect is fairly limited.

In this paper we combine Prussian county data from three different censuses (1816, 1849, and 1867) in order to estimate the relationship between parental schooling and fertility on the eve of the demographic transition. Prussia offers an important opportunity to analyze the relationship between parental education and fertility because of her strong focus on mandatory primary education starting from the 18th century (Melton, 1988) and high-quality data on school enrolment and fertility. As the censuses provide data on school enrolment by gender, we shall focus our analysis exclusively on the enrolment of girls. However, given the very high correlation between male and female enrolment rates, we cannot separate identify the effect of women's and men's education in a regression

[1]See for example the works of Gutmann and Watkins (1990), Rindfuss, Morgan, and Offutt (1996), and Caldwell (1999)

analysis. Our conclusions on the effect of women's education on their fertility should therefore be interpreted as the effect of parental education on fertility.

In studying the effect of parental education on fertility we take into account several demand and supply factors such as the women's age at marriage, employment opportunities for women outside agriculture, and mothers' preference for children education proxied by the primary school enrolment rates at the time when the children enter school age. We find that, despite controlling for exhaustive demand and supply factors, women's formal education has a significant *residual* negative impact on fertility. This relationship is robust to the introduction of measures for child and maternal mortality, and migration, and to accounting for spatial autocorrelation.

In order to address a potential problem of omitted variable bias due to unobserved heterogeneity, we adopt an instrumental variables approach using landownership inequality in 1816 as an instrument for parental education (Galor, Moav, and Vollrath, 2009; Becker, Cinnirella, and Woessmann, 2010). We exploit exogenous variation of primary school enrolment rates driven by the opposition to education of the landed nobility that had no interest in having an educated labor force (Melton, 1988). The instrumental variables estimates suggest that the negative effect of parental education on fertility is causal and that OLS underestimates the true effect.

2 Previous work

The European Fertility Project (EFP), coordinated in Princeton in the 1960s and 1970s, aimed at studying the fertility patterns of most Western European countries (Coale and Watkins, 1986). The EFP concluded that the spread of new moral and cultural norms together with birth control technology were responsible for the fertility decline in Europe.[2] In particular, Knodel (1979) using family reconstitution data studied the transition from natural fertility to family limitation in a sample of 12 German villages. Knodel finds a strong heterogeneity in the timing of the emergence of family limitation but he cannot identify the factors that could explain such diversity.

[2]See Brown and Guinnane (2007) for a critique of the empirical approach and the conclusions of the European Fertility Project.

Previous studies have shown that employment opportunities for women and cultural factors might have shaped the demographic transition at the end of the nineteenth century (Crafts, 1989; Galloway, Hammel, and Lee, 1994). In a recent paper, Dribe (2009) analyzes the factors that characterized the fertility transition in Sweden. Using county-level data for the period 1880-1930, the author finds that lower child mortality, higher urbanization, and stronger "educational orientation" were associated with lower marital fertility. Dribe measures educational orientation through the ratio of number of teachers over 100 children aged 7-14. That variable is meant to be an indicator of the importance of child quality and therefore to control for the child quantity-quality trade-off. Interestingly, Dribe finds that only variation in the levels of education and not variation over time is relevant for explaining decline in fertility (Dribe, 2009, p.83).

There are other studies that further investigated the determinants of the demographic transition in Germany and reached quite different conclusion with respect to the EFP's one. Galloway, Hammel, and Lee (1994) analyze county data for Prussia starting from the last quarter of the 19th century. Their results are very much in line with those of Dribe for Sweden. In fact, in their regression they also have an educational variable constructed as the ratio of teacher per 100 individuals aged 6-13 that has a negative effect on the marital fertility rate. Brown and Guinnane (2002) studied the fertility transition in Bavaria, a German region characterized by strong Catholicism and a relatively rural economy. They use census data for the period between 1880-1910 and find that Catholicism had a large and growing impact on fertility, stressing the importance of social norms in fertility regulation. They find also differential fertility by occupation and a significant effect of wages, which speaks in favor of an "adjustment" interpretation of the demographic transition. Important with respect to our paper, Brown and Guinnane do not include measures of education (or schooling) because of lack of such information. More in general, all these studies do not include a direct measure (or a proxy) for the mothers' education.

Recent theoretical (Galor and Weil, 2000; Galor and Moav, 2006) and empirical works (Becker, Cinnirella, and Woessmann, 2010) have analyzed the relationship between the quantity-quality trade-off of children and fertility restraint for the period before and during the demographic transition. Other theoretical papers elaborate models where human capital is a crucial ingredient, though not through its association with fertility, but rather with life expectancy (see for instance Cervellati and Sunde (2005)). In our paper, we show that female formal education played an important role in fertility restraint, independently from intervening factors such as age at marriage, employment opportunities for women outside agriculture, and preferences for having educated children.

3 Demographic patterns in Prussia

In the framework of the European Fertility Project (EFP), Knodel (1974) studied the demographic transition in Germany. Using the arbitrary definition of a 10 percent decline of the index of marital fertility rate (I_g), Knodel identifies the onset of the fertility transition in Germany at 1895 (Knodel, 1974).

In Figure 1 we show the trends of the crude birth rate, mortality rate, and marriage rate for Prussia in the 19th century. The figure shows relatively stable trends for the first three quarters of the century. In fact, after decreasing in the 1820s, the crude birth rate fluctuates around 40 births per 1000 people; similarly, the mortality rate fluctuates between 25 and 30 deaths per 1000 people. Mortality peaks in 1831, when Prussia was hit by a cholera epidemic, in 1848, in conjunction with the political unrest, and in 1866 during the Austrian-Prussian war. With the exception of 1866, the birth rate mirrors the swings of the mortality rates.[3] Only around the last two decades of the 19th century, birth and mortality rates point to a secular decline. At the bottom of Figure 1, we also show the trend in marriage rates which remained fairly constant oscillating at around 9 marriages per 1000 people.

– Insert Figure 1 here –

The birth rate levels shown in Figure 1 are consistent with the European Marriage Pattern characterized by high fertility within marriage but relatively low levels of birth rates.[4] Other characteristics of the European Marriage Pattern were a late average age of first

[3]The average in the period 1816-1875 is 27‰.
[4]The biological maximum is considered to be around 60 births per thousand.

marriage and a relatively high share of unmarried women. Knodel studies family reconstitution from 12 German villages and reports for the period 1750-1899 an average age at first marriage which swings around 26.9 for women and 29.4 for men (Knodel, 1979, Table 1, p. 496). We shall see that, in 1849, a considerable share of women married after age 30 and that it positively correlates with the (stock) share of unmarried women.

4 Data and identification strategy

Regarding the causes of the demographic transition, Knodel (1974), and the European Fertility Project in general attributed much importance to the processes of innovation and diffusion of knowledge about contraception, downplaying the role of any socio-economic factor. This view has been firmly criticized and, more recently, several studies have shown the importance of socio-economic factors as determinants of the fertility decline (Galloway, Hammel, and Lee, 1994; Galloway1998; Brown 2007; Becker, Cinnirella and Woessmann 2010). In particular, what has been criticized is the choice of relatively large units of analysis. In the case of Germany, the EFP used 30 *Regierungsbezirke,* which are large administrative districts with roughly half a million inhabitants and comprising more than 10 counties (*Kreise*), on average. Similarly to the study of Galloway, Hammel, and Lee (1994) and Galloway, Lee, and Hammel (1998), in our study we use more disaggregated data, namely county level data (*Kreis*) for the period before the onset of the Prussian demographic transition.

The 1816 Prussian census contains information on the number of children enrolled in primary schools by county. Our main variable of interest—female enrolment rates—is constructed as the number of girls enrolled in primary school in 1816 over the total number of girls aged 6-14. We shall then consider female enrolment rates in 1816 as a proxy for the level of education of future mothers.

Prussian census data do not provide detailed information on age at marriage. Yet, the 1849 census reports the (flow) number of marriages in 1849 by three age categories: women younger than 30, between 30 and 45, and older than 45.[5] Our measure for age at marriage is constructed as the share of women who married when older than 30. The

[5]The same categorization is available also for men.

variable is thus bounded between zero and one. A value of the variable close to one (zero) indicates a tendency to marry later (earlier).[6] According to our data, on average, around 23 percent of the marriages in 1849 involved a woman above the age of 30. The variable presents also a considerable variation as levels range from about 0.10 to 0.46.

We also have a (stock) variable for the share of married women in 1849 computed as the ratio of women in wedlock over the total number of women aged 15-45. According to this variable, about 70 percent of the women lived in a marriage (s.d. 0.06), with the variable ranging from a minimum of 0.43 to a maximum of 0.85. This variable shall be used as a proxy for the nuptiality rate. It is interesting to note that there is a negative correlation between age at marriage and the stock share of married women ($\rho=-0.38$). It suggests that in those counties where the average age at marriage was higher the celibacy rate was also relatively high.

Ideally, we would like to have the number of children of the women who were enrolled in primary schools in 1816 (and for whom we also have an indication of their age at marriage in 1849). Unfortunately, we cannot observe fertility for exactly these cohorts but we have detailed population censuses, which allow us to link the number of children in 1867 with female education levels in 1816.[7] Thus, as fertility measure we use the child-woman ratio constructed as the number of children aged 10-19 over the number of women aged 40-69 in 1867. We use the number of children aged 10-19 because this age group contains, amongst others, those children who were born in 1849—year for which we observe most of the demand and supply factors. Most important, cross-county differences in this age group are expected to mirror differences in fertility and, in particular, in family size. The number of women aged 40-69 in 1867—the denominator of our child-woman ratio—is expected to capture the female cohorts who were in school in

[6]Remarriage might be an issue here as we only observe the number of marriages at one point in time (in 1849) and we do not know whether it is a first marriage. In fact, we know that remarriage rates were not a trivial number. Knodel (1974) reports a share of remarriages between 15 and 25 percent of all the marriages and that men were more likely to remarry than women. However, as long as remarriage rates do not differ systematically across counties, that should not affect our analysis.

[7]Since we also have the female enrolment rates in 1849, we could compute the female enrolment rates in 1832 interpolating the rates in 1816 and 1849. In this way, those enrolled in primary school in 1832 (aged 6-14) would be 23-31 in 1849 and 41-49 in 1867. We can show that all the results provided in the following analysis hold when using the 1832 approximation.

1816. In fact, women between ages 40-69 in 1867 were between 22-51 in 1849 and between 0-18 in 1816.[8]

In sum, variation across counties of the child-woman ratio in 1867 is expected to capture variation in fertility of mothers (*i*) with an educational level proxied by the female enrolment rates in 1816, and (*ii*) whose demand and supply factors are captured by our set of control variables for 1849.[9]

As mentioned above, the denominator of the child-woman ratio contains women of a relatively old age given the period considered here. Therefore, female mortality is a crucial issue. According to our data, average female life expectancy at age 25 in 1849 was 58.7 (standard deviation 4.4). In general there is a positive relationship between life expectancy and education. In our case the correlation coefficient between female primary school enrolment rate in 1816 and life expectancy at age 25 in 1849 is 0.35. That is, women with a formal education were more likely to live longer, which means that they are "over-represented" in our child-woman ratio in 1867. Assuming a negative relationship between female education and fertility, that would bias our estimates toward more negative estimates. Additionally, women giving birth to more children were more likely to die in childbirth and that would also affect our dependent variable. The 1849 census contains information on the number of women who died at child birth, which allows us to construct a maternal mortality ratio.[10] Our data show that around 832 mothers died per 100,000 live births.[11] We shall show that controlling for female lifeexpectancy at age 25 and the maternal mortality ratio does not affect our findings.

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[8]Notice that when using women aged 40-59 as denominator of the child-woman ratio, results are identical.

[9]Another important assumption here is that between 1849 and 1857, counties did not change systematically their age at marriage pattern. In fact, the children aged 10-19 we observe in 1867 are also the product of marriages, *not observed*, that occurred between 1850 and 1857. If the pattern of age at marriage across counties changed systematically during this period, the coefficient we estimate would be no longer informative. However, there is no evidence of systematic changes in age at marriage in such a short period of time.

[10]The maternal mortality ratio is defined as the ratio of the number of maternal deaths per 100,000 live births.

[11]To provide an order of magnitude, according to the United Nations Population Fund (UNFPA), in 2005 the maternal mortality ratio for developing countries was 450.

– Insert Table 1 here –

5 The determinants of fertility

Easterlin and Crimmins (1985) suggest that the number of children born in a family is determined by 3 factors: the demand for children, the supply of children, and the cost of fertility regulation. We shall also use this theoretical framework when choosing the covariates of our regression analysis and for the interpretation of the results. The merit of such a supply-demand approach is to conjugate the dichotomy between economic (adjustment) and cultural (innovation) factors that characterized the literature on the demographic transition (Friedlander, Okun, and Segal, 1999).

The demand for children depends on family income and the relative cost of children. If we consider children as normal goods, we expect to find a positive effect of income on fertility. We do not have a direct measure for income, but we can control for the industrialization level (and urbanization), which is generally a good proxy for the income level of the county. In particular, we use the share of the population employed in manufacturing.

Recently, unified growth theory[12] used extensively the concept of the quantity-quality trade-off of children in order to model the demographic transition and therefore the transition from stagnation to growth.[13] The theory argues that, as returns to education increased due to technological developments, families shifted their preferences toward higher quality of children, which eventually affected negatively the demand for children. In the standard model of Becker and Tomes (1976) the shadow price of child quality is positively related to the number of children (and the other way around). Therefore, a higher demand for child quality increases the cost of child quantity and therefore reduces fertility. In a recent paper, Becker, Cinnirella, and Woessmann (2010) provide an empirical test of the child quantity-quality tradeoff in Prussia before the demographic

[12]See Galor (2005) for an exhaustive review of the theory.
[13]About the quantity-quality trade-off of children see the seminal contributions of Becker and Lewis (1973) and of Becker and Tomes (1976).

transition. In this study, we take into account parental tastes for education of their children, and therefore the child quantity-quality trade-off by controlling for the level of education in 1864.

It has been shown that employment opportunities for women outside agriculture—the opportunity cost of a child—significantly influence fertility levels. Assuming that the time devoted to child rearing cannot be spent in the labor market, higher employment opportunities for women should be negatively related to fertility. We include two variables to proxy for employment opportunities for women outside agriculture: (i) the ratio of individuals employed in textile factories over the number of women (15-60) and (ii) the share of individuals employed as craftsmen in the textile sector in 1849.[14]

Easterlin and Crimmins (1985) define the supply of children as the number of surviving children a couple would get if they made no conscious efforts to limit the size of the family. It therefore reflects natural fertility and child survival rates. To take into account these factors, in our regression analysis we control for age at marriage and child mortality (0-5). We expect age at marriage to be negatively correlated with fertility as later age at marriage implies a shorter duration of marriage. In addition, lower child mortality is expected to be negatively correlated with total fertility as lower child mortality allowed families to be more effective in reaching the desired number of children and reduced any “hoarding” effect (Doepke, 2005). Finally, we control also for religion in order to account for cultural differences that may also have contributed to the spread of new attitudes towards fertility control procedures.[15]

6 Regression analysis

Standard economic models and empirical evidence suggest that mothers with higher level of education get married later, have higher employment opportunities, have a higher relative wage, have a relatively stronger preference for child quality, and have higher consumption aspirations. All these factors, in turn, are expected to lower the demand for children. We expect therefore that the effect of women’s formal education on fertility is to a large extent reduced by these intervening factors.

[14]Unfortunately the 1849 census does not provide gender specific employment figures.
[15]See Coale and Watkins (1986) on the conclusions of the Princeton Fertility Project.

We first proceed estimating the relationship between women's formal education and fertility by standard OLS controlling for variables such as women's age at marriage, employment opportunities outside agriculture, and preference for child quality. More formally:

$$fertility_{i,1867} = a_i + \beta\, edu_{i,1816} + \mathbf{X}_{i,1849}\,\lambda + \mathbf{Z}_{i,1849}\gamma + \varepsilon_i \qquad (1)$$

where *edu* is the share of girls (6-14) enrolled in primary school in 1816, β the parameter of interest, **X** and **Z** respectively a vector of demand and supply variables for 1849, and the subscript *i*=1,2,…,334 indicates the county (*Kreis*).

6.1 Fertility and women's education

In Table 2 we report the OLS estimates of equation (1). We present various specifications where we sequentially introduce more control variables in order to study how the effect of women's education changes when adding further intervening factors. Note that the model includes also enrolment rates in 1849 in order to account for education preferences of parents, i.e. the quantity-quality trade-off of children. In addition, we control also for maternal mortality ratio in 1849 to correct for differential in female mortality which could affect the denominator of our dependent variable.[16]

In column 1 one can immediately see that women's formal education has a large and significant negative effect on fertility. An increase of the girls' enrolment rate by 10 percentage points is associated with a decrease of around 6 children per 100 women. This effect is very large as it implies that one standard deviation increase in the enrolment rate is associated with a decrease of the child-woman ratio of about 0.44 standard deviations. This strong correlation is corroborated by the high level of the R-squared already in column 1, which implies that female schooling levels in 1816 explain around 20 percent of the cross-county variation of child-woman ratio in 1867.

[16]Given the relatively strong correlation with maternal mortality, the coefficient for female life expectancy at age 25 is always not statistically significant. For this reason we decided to control only for maternal mortality.

The coefficient remains significant and of similar magnitude when controlling for urbanization, industrialization, religion, and the marriage rate (column 2). An important result comes from the estimates of column 3: Employment opportunities for women outside agriculture have strong negative effects on fertility. In particular, employment levels of craftsmen in the textile sector are strongly negatively correlated with fertility. The possibility to earn a (higher) wage increases the opportunity cost of children and therefore depresses the demand for children. Our result is in line with the study of Schultz (1985) that, using county-level data for Sweden, reports a causal negative effect of higher female relative wages on fertility.[17] Yet, the effect of women's education maintains its magnitude and significance.

Similarly, we find that women's age at marriage has a significant negative effect on fertility (column 4). The remarkable increase of the R-squared stresses the importance of age at marriage in explaining the variation of fertility. Notice that we do not claim here that age at marriage was deliberately used to limit fertility. Generally, the theory assumes that age at marriage is exogenous to the decision on deliberate fertility control (Easterlin and Crimmins, 1985). Yet, to the extent that education and age at marriage are strongly correlated, it is important to control for women's age at marriage if we want to isolate the effect of women's education on fertility. In fact, controlling for age at marriage the coefficient for women's education is still large and highly significant.

Educated mothers are likely to have stronger preference for the education of their children. Therefore, the estimated effect of women's education might then simply reflect such a preference for quality to the detriment of quantity. There is some evidence which shows that investment in children in form of education were complementary to investment in better nutrition (Weir, 1993; Hatton and Martin, 2009). Becker, Cinnirella, and Woessmann (2010) showed empirically the importance of the quantity-quality trade-off of children before and during the demographic transition in Prussia. In order to take

[17]Employment opportunities in the textile sector might capture also children employment opportunities, which would have a positive effect on fertility. We are not aware of any estimate of child labor in Prussia for the period under consideration here. However, the first Prussian Child Labor Law was passed in 1839 and the Prussian Statute in 1853. Therefore, the period under investigation here is likely characterized by declining rates of child labor. This is also witnessed by the increasing enrolment rates in primary school that reached the average value of 80 percent in Prussia 1849. This would support the argument of an increasing relative cost of children.

into account this trade-off, in column 5 we control for the primary school enrolment rates in 1849. Indeed, we find that the enrolment levels in 1849 have a significant negative impact on realized fertility. Most important, controlling for the quantity-quality trade-off reduces the effect of female education by almost 30 percent.[18] This result is then consistent with the hypothesis that mothers with a formal education tend to have a higher preference for child quality.

There is a large literature, both theoretical and empirical, which stresses the importance of child mortality in explaining fertility restraint (Crafts, 1989; Boyer1989).[19] In column 6 we introduce a control for child mortality (age 0-5) in 1849. Unexpectedly, we find a negative sign of the coefficient which becomes even larger, but still insignificant, when controlling for maternal mortality in column 7.[20] We do not have an explanation for this result which, actually, is common to other studies. In fact, whereas Dribe (2009) finds a positive effect of child mortality on marital fertility (both in the levels and in the panel structure), Brown and Guinnane (2002, Table 2)[21] and Galloway, Hammel, and Lee (1994, Table 3, column 2) estimate a negative effect of infant mortality rate, though not always significant.

Finally, in column 7, we introduce a control for maternal mortality to account for differential mortality levels that could affect the number of women at the denominator of our dependent variable. Clearly, this variable is endogenous to the child-woman ratio, as a higher number of births increases the probability to die at childbirth. That explains the significant positive coefficient linked to the variable. However, for the sake of our argument, it is important to notice that even after controlling for maternal mortality, the effect of women's education remains unaltered. In sum, we find that women's age at marriage, employment opportunities for women outside agriculture, and the quantity-quality trade-off of children had, respectively, a strong impact on realized fertility on the

[18]Similarly to other studies, we have also used the number of school teachers per capita as an indicator for preferences for child quality. The results are qualitatively the same. Yet, we believe that controlling for the number of children attending school in 1849 is a better measure for the child quantity-quality trade-off.

[19]The European Fertility Project concluded that infant mortality rate did not play a major role in the European fertility decline (van de Walle, 1986).

[20]Notice that the negative effect persists even if we use the infant mortality rate or mortality rates for different ages.

[21]They instrument infant mortality rate with an environmental variable such as elevation.

eve of the demographic transition in Prussia. Yet, even after controlling for these factors, we find that women's formal education has a *residual* significant negative effect on fertility. It is important to note that this effect is economically non-trivial: in our full specification in column 7, one standard deviation increase in the girls enrolment rate in 1816 is associated with a decrease of the child-woman ratio in 1867 of about 0.3 standard deviations.

6.2 Robustness checks

In table 3 we present some robustness checks. In column 1 we introduce a control for population density. The coefficient of our variable of interest remains unaffected and the explanatory power of the model does not improve significantly.

As we are "linking" information from three different censuses, systematic differences across counties in migration patterns may constitute a problem. In fact, migration generally concerned young, single males (Boyer and Williamson, 1989). Therefore, if parents considered children as assets for their old age period, higher out-migration rates might be negatively correlated with fertility. On the other hand, a positive balance of immigrants might have had a negative effect on fertility as migrants tended to get into marriage later.[22] Thus, in column 2, we introduce a measure for net migration.[23] Unfortunately we have detailed data on migration only for the last 2 decades of the 19th century. Thus, we use net migration in 1880 constructed as the difference between immigrants and emigrants over the reference population (in 1000).[24] We find that counties with a higher net migration (therefore with relatively more immigrants than emigrants) tend to have lower fertility. Yet, our coefficient of interest remains unaffected in its magnitude and significance.

[22]In fact, we find a slightly positive correlation between age at marriage and our variable for net migration in 1880 (ρ=0.12).
[23]We lose one observation because of problematic matching of changed county borders.
[24]We could also use net migration for the year 1862 but this variable is less precise as, contrary to 1880, it does not consider unofficial immigrants. However, estimates using net migration in 1862 are virtually identical.

Recently, Alesina, Giuliano, Nunn (2010) suggested that, consistent with the existing anthropological evidence, in societies with a traditional use of animal plough agriculture the division of labor is split along gender lines, with men working outside of the home in agriculture and industry, and women working within the home. The idea is that animal plough agriculture was heavier work, more suited for men. They document the persistence of these cultures over time by examining the relationship between historic plough use and contemporary female labor force participation and individuals' attitudes about the role of women. In column 3, we follow this line of thought and control for cattle per woman as a measure of the type of agriculture prevalent in an area. This control variable turns out not to be significant.

The maps of Figure 3 and 4 suggest that geographical clustering could be an issue as, for instance in the case of fertility, there is an East-West divide with higher levels in the East. Cultural and institutional factors are likely to be behind such geographical stratification. In column 4, we add measures of latitude and longitude (in radians) in order to test whether the estimated association between women's education and fertility holds independently of broad geographic patterns. We find that higher latitude is associated with higher fertility, whereas higher longitude is associated with lower levels of fertility. These geographical controls, especially latitude, have a large effect on fertility. Further, they significantly reduce the effect of female education, as a one-standard deviation increase in girls' enrolment rate in 1816 is associated with a decrease of the child-woman ratio in 1867 by about 0.2 standard deviations. However, though smaller, the negative effect of women's formal education on realized fertility is still highly statistically and economically significant.[25]

Finally, in column 5 we present estimates using a different variable for employment opportunities for women outside agriculture. Contrary to 1849, for 1867 we observe the share of women employed in industry. Clearly, this is a better variable for employment opportunities for women outside agriculture as it takes into consideration the actual industrial female labor force; on the other hand, we observe this variable only when the

[25] We further investigated the effect of geographical clustering by estimating models that explicitly take into account spatial autocorrelation. Our findings (not reported) are robust in spatial lag and spatial error models (see Anselin, 1988 and Anselin and Hudak, 1992).

decision about fertility has already been made. However, as expected, we find a strong negative effect of the female employment variables for 1867 but the coefficient for women's education is still highly significant.

In some studies, the variable for female literacy has been intended as a proxy for knowledge of contraception methods (Boyer and Williamson, 1989). Therefore, one could argue that the estimated effect of mothers' education on fertility is capturing, to a large extent, the relationship between contraception and fertility. In order to test this hypothesis, we used *changes* in illegitimacy rates as a proxy for the use of contraceptive methods (Shorter, Knodel, and van de Walle, 1971). In fact, we agree with Boyer and Williamson (1989) and Crafts (1984) who argue that cross-sectional differences in illegitimacy rates mirror not only the use of contraceptives but also, for instance, the extent of non-marital sexual activity. Thus, we test whether controlling for change in illegitimacy rates in the period 1849-1862 affects the estimated effect of women's education. We find that the coefficient for women's education remains unchanged both in its magnitude and significance.[26]

7 The causal effect of women's education

So far our estimates have shown a robust statistical correlation between women's education and fertility. However, our results do not necessarily show a causal relationship, as the existence of unobserved county-specific variables, which are correlated with both women's education and fertility could bias our estimates. Therefore, we adopt an instrumental variables approach, which uses exogenous variation in enrolment rates to estimate its causal effect on realized fertility. In particular, we use landownership inequality in 1816 as an instrument for women's enrolment rates in primary schools.

The idea of using landownership inequality builds on Galor, Moav, and Vollrath (2009) who present a theoretical model where inequality in the distribution of landownership negatively affects the implementation of human-capital-promoting institutions. This is

[26]Estimates not reported here but available upon request.

due to the low complementarities between land and human capital. Galor, Moav, and Vollrath (2009) also provide empirical evidence for the United States in the 20th century corroborating their prediction. In the case of Prussia, there is substantial anecdotal evidence that noble landowners (Junker) opposed the construction of rural schools or did not make controls to enforce school attendance (Melton, 1988).

For their empirical evidence, Galor, Moav, and Vollrath (2009) use the share of land held by large landowners. The 1816 census provides information on the number of land holdings grouped in three categories: 0-15, 15-300, or greater than 300 *Morgen*.[27] That information allows constructing an index of landownership inequality as the ratio of the largest land holdings over the total number of holdings.[28]

So far, our dataset was constructed according to the county-borders of 1849, which allowed us to use 334 observations. The information on land holdings in 1816 cannot be fully matched with the 1849 borders. In fact, between 1816 and 1849 Prussia experienced significant changes in county-borders. Most notably in East Prussia, large counties have been often split into smaller counties.[29] Therefore, in order to use the information on landownership in 1816 we follow two alternative approaches: (i) for those observations that cannot be matched with the 1849 borders, we use landownership inequality in 1849; (ii) we adjust all our variables to the county-borders in force in 1816. Whereas with the former approach we keep the number of observations equal to 334, with the latter strategy our dataset is reduced to 267 observations.

The exclusion restriction for the validity of the IV estimates is that landownership inequality in 1816 is not *directly* related to later fertility outcomes. Bengtsson and Dribe (2006) show that total marital fertility, as well as age-specific marital fertility, is very similar across socioeconomic groups with different landownership patterns in pre-transition Sweden. On the contrary, Brown and Guinnane (2002) find that in rural Bavaria farm size is negatively correlated with marital fertility. However, it is important to note that both studies analyze the effect of farm size and do not investigate the role of *inequality* in the distribution of land, which is the relevant measure of our identification

[27]One *Morgen* is equal to about 0.25 hectares.
[28]Becker, Cinnirella, and Woessmann (2010) used variation in landownership inequality in 1849 in order to identify exogenous variation in enrolment rates in 1849.
[29]A further division of the counties took place after unification in 1871.

strategy. In our case, though the landed nobility had a discretional power regarding the marriages of laborers, it seems unlikely that, once given the concession to marry was granted, the landowner could influence the level of marital fertility. Therefore, to the extent that we control for the age at marriage and for the share of married couples, the exclusion restriction should hold. In addition, even if we suppose that landownership inequality in 1816 had a *direct* effect on fertility, that would affect fertility in 1816, which is a variable we include in our regression. In fact, our IV regressions include the child-woman ratio in 1816 constructed as the ratio of children aged 0-7 over the number of women aged 15-45 in 1816.

In Table 4 and 5, we report the IV estimates for both approaches discussed above. For comparison, we also report OLS estimates using the IV regression samples and specifications. In both cases, first stage estimates show a significant inverse relationship between landownership inequality and female enrolment rates in 1816, with a reassuringly high F-statistics of the first stage. Second stage estimates show that the effect of women's education on their fertility is causal and larger with respect to OLS estimates. It is important to note that the effect of women's education is highly significant also when we adjust to the 1816 county-borders, even though we only have 267 observations.

8 Discussion

Our estimates imply that women's education has a significant negative effect on realized fertility, independently of the fact that more educated women tend to get married later, have more employment opportunities, and have a stronger preference for the education of their children. Instrumental variables estimates suggest that this effect is causal. This result is important in its own right as it sheds light on a determinant of fertility decline, namely women's education, which has been largely neglected in the historical literature.

Yet, our main finding opens up another crucial question: What is the mechanism that is driving the negative relationship between women's education and fertility? Easterlin and Crimmins (1985) discuss the various effects that formal education might have on fertility control. On one hand, formal education improves health conditions and therefore it could have a positive effect on fertility enhancing the "potential supply" of children. On the other hand, education lowers the costs of fertility regulation providing more information about means of fertility control. Following Crafts (1984) and Boyer and Williamson (1989), we used variation over time in illegitimacy rates as a proxy for the use of contraceptive methods. The effect of women's education remained highly significant, both economically and statistically. Though far from conclusive, this suggests that female education is not (only) capturing better access to information about contraception.[30] Furthermore, the results of the spatial analysis seem to rule out any "local spillover" explanation, as the negative relationship between mothers' education and fertility holds also when accounting for spatial autocorrelation.

A more plausible explanation for our *residual* effect of women's education regards the female relative wage. It is hypothesized that an increasing female wage relative to that of men increased the opportunity cost of children and therefore reduced fertility. Indeed, this trend in the relative wage of females might have been induced by increasing levels of women's education. In fact, Dribe (2009) finds for Sweden that increasing female relative wages were associated with declining fertility among women over 35. This result is consistent with Schultz (1985) who finds that a quarter of the decline in the Swedish total fertility rate from 1850 to 1910 can be explained by the 10 percent rise in the female to male wage ratio. In our regression analysis we do not have any direct measure for the female relative wage and we only control for employment opportunities outside agriculture. We cannot therefore reject the hypothesis that our estimated effect of women's education captures to a large extent the effect of a higher female relative wage.

However, another possible explanation, which received little attention in the literature, is the availability of new goods. Standard economic theory assumes that children are normal goods and that consumption goods and children are gross substitutes. In a recent paper Guzman and Weisdorf (2010) formally show how an increase in consumption goods variety may depress the demand for children. Under certain assumptions, the introduction of new consumer goods to markets can have the effect of turning tastes away from children, toward consumption of previously unavailable items. In our case, formal education may operate by shifting preferences from

[30]In addition, there is some evidence according to which methods of fertility control were known and available at a reasonable cost. See for example Bengtsson and Dribe (2006) on the case of Sweden.

children to consumption goods as educated women develop higher (or different) consumption aspirations (de Vries, 2008; Leibenstein, 1975; Easterlin and Crimmins, 1985).[31] Knodel (1974, p. 127), analyzing the decline of fertility in Germany, argues that "improvements in the standard of living were supposed to instill mobility aspirations as well as desires for even greater material wealth and the limitation of family size was seen as one way to realize these goals". Clearly, an empirical test of the "change of preferences" hypothesis is hard to implement with county-level data. Data on consumption patterns at a disaggregated level are very scarce and therefore a thorough test of this hypothesis is at the moment not possible. Nevertheless, the study of the relationship between higher levels of education and consumption patterns deserves further research.

9 Conclusion

There is a growing theoretical and empirical literature bringing together the Industrial Revolution and the Demographic Transition in a unified framework. In particular, scholars are attempting to understand the interrelationships between factors that characterized the Industrial Revolution and those that triggered the demographic transition.

In this paper, we contribute to the literature shedding light on the relationship between women's formal education, measured in terms of school enrolment rates, and their fertility. Linking county-level data from three different censuses, we show that increases in women's education played a substantial role in reducing fertility on the eve of the Demographic Transition in Prussia. Least squares estimates show that an increase of girls' enrolment rates by one standard deviation is associated with a decrease in realized fertility between 0.2 and 0.3 standard deviations. Part of this effect is explained by later age at marriage and by better employment opportunities for women outside agriculture for more educated women.

[31] Ogilvie (2010) argues that before 1800, the Industrious and Consumer Revolutions were held back in continental Europe, largely due to the influence of guilds. The Stein-Hardenberg Reforms in the first decade of the 19th century abolished, amongst others, guild restrictions and thus removed important obstacles for the Consumer Revolution.

Previous research has shown to which extent the quantity-quality trade-off of children affected fertility levels in Prussia. In line with those results, our estimates suggest that mothers with a formal education have stronger preferences for the education of their children. In fact, once we control for the child quantity-quality trade-off, the effect of women's education on their fertility is reduced by almost 30 percent.

However, even after controlling for classical fertility demand and supply factors, we find a robust *residual* negative effect of women's education on their fertility.

In order to discard possible biases coming from unobserved heterogeneity, we adopt an instrumental variables approach. We use exogenous variation in enrolment rates driven by landownership inequality in 1816. Inequality in the distribution of land negatively affects the implementation of human-capital-promoting institutions given the low complementarities between agriculture and education. The instrumental variables estimates suggest that female education has indeed a causal negative effect on fertility.

This result is important in its own right as it quantifies the role of women's education in reducing fertility, a factor that has been so far widely neglected in the analysis of the demographic transition. In addition, our finding opens up an intriguing question, namely on the mechanism that is at work behind the inverse relationship between women's education and realized fertility.

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Tables and figures

Table 1: Summary statistics

Variable	*Mean*	*Std. Dev.*	*Min.*	*Max.*	*N*
Child-woman ratio (1867)	1.714	0.268	1.016	2.54	334
Female enrolment rate (1816)	0.545	0.21	0.02	0.939	334
Age at marriage (1849)	0.226	0.061	0.09	0.464	334
Employment in textile factories (1849)	0.149	0.209	0.013	1.747	334
Textile Craftsmen (1849)	0.022	0.025	0.003	0.246	334
Women in industry per capita (1867)	0.007	0.009	0	0.063	334
Enrolment rate (1864)	0.753	0.104	0.438	1.201	334
Child mortality (1849)	7.50	2.35	3.36	14.91	334
Net migration per 1000 inhabitants (1880)	-1.686	3.674	-32.219	2.374	333
Urban share (1849)	0.246	0.186	0	1	334
Share in industry (1849)	0.03	0.029	0.006	0.322	334
Share Protestants (1849)	0.605	0.394	0.002	0.999	334
Share married women (1849)	0.701	0.058	0.431	0.854	334
Landownership inequality (1816-49)	0.017	0.02	0	0.148	334
Maternal mortality ratio (1849)	829.219	344.993	0	2049.78	334
Total population (1816)	30459	14531	7732	182001	334
Total population (1849)	48649	26899	13647	423902	334

Note: Child-woman ratio is the number of children aged 10-19 over the number of women aged 40-69. Female enrolment rate is the ratio of girls enrolled in primary and middle schools over the number of girls aged 6-14. Age at marriage is defined as the share of women who married at age older than 30.

Table 2: The effect of mothers' education on fertility

Dep. Var.: Child-woman ratio (1867)	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Female enrolment rate (1816)	-0.561***	-0.620***	-0.597***	-0.539***	-0.342***	-0.348***	-0.344***
	(0.057)	(0.062)	(0.061)	(0.058)	(0.067)	(0.068)	(0.069)
Employed in textile factories			-0.281***	-0.197**	-0.176**	-0.170**	-0.158**
(1849)			(0.101)	(0.089)	(0.086)	(0.078)	(0.079)
Age at marriage (1849)				-1.832***	-1.687***	-1.638***	-1.610***
				(0.207)	(0.220)	(0.216)	(0.214)
Enrolment rate (1864)					-0.730***	-0.858***	-0.797***
					(0.152)	(0.180)	(0.179)
Child mortality rate (1849)						-1.496**	-1.726***
						(0.589)	(0.606)
Maternal mortality ratio (1849)							0.000*
							(0.000)
Urban share (1849)		-0.079	-0.025	0.056	0.131	0.182*	0.200**
		(0.085)	(0.090)	(0.079)	(0.087)	(0.092)	(0.097)
Share in industry (1849)		0.642	1.145***	0.749*	1.043***	0.925**	0.961**
		(0.425)	(0.393)	(0.383)	(0.369)	(0.367)	(0.381)
Share Protestants (1849)		0.044	0.021	-0.087**	-0.116***	-0.118***	-0.116***
		(0.035)	(0.036)	(0.035)	(0.037)	(0.038)	(0.038)
Share married women (1849)		0.273	0.344	-0.111	0.296	0.359	0.362
		(0.324)	(0.323)	(0.265)	(0.309)	(0.313)	(0.314)
Constant	2.020***	1.835***	1.800***	2.546***	2.658***	2.805***	2.694***
	(0.035)	(0.225)	(0.225)	(0.207)	(0.226)	(0.235)	(0.234)
Observations	334	334	334	334	334	334	334
R-squared	0.193	0.209	0.251	0.379	0.428	0.442	0.450

Note: Robust standard errors in parenthesis. *** p<0.01, ** p<0.05, * p<0.10. Child-woman ratio is the number of children aged 10-19 over the number of women aged 40-69. Female enrolment rate is the ratio of girls enrolled in primary and middle schools over the number of girls aged 6-14. Age at marriage is defined as the share of women who married at age older than 30.
Source: Own estimates.

Table 3: The effect of mothers' education on fertility—Robustness checks

Dep. Var.: Child-woman ratio (1867)	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*
Female enrolment rate (1816)	-0.343***	-0.315***	-0.313***	-0.248***	-0.259***
	(0.069)	(0.068)	(0.067)	(0.068)	(0.069)
Employed in textile factories (1849)	-0.160**	-0.148*	-0.147*	-0.145*	
	(0.079)	(0.079)	(0.080)	(0.079)	
Age at marriage (1849)	-1.615***	-1.552***	-1.558***	-1.921***	-1.916***
	(0.214)	(0.211)	(0.219)	(0.237)	(0.236)
Enrolment rate (1864)	-0.783***	-0.695***	-0.699***	-0.603***	-0.587***
	(0.180)	(0.182)	(0.182)	(0.224)	(0.220)
Population density (1849)	-0.009	-0.011	-0.011	-0.019**	-0.017**
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Net migration per 1000 inhabitants		-0.012***	-0.012***	-0.009**	-0.009**
(1880)		(0.004)	(0.004)	(0.004)	(0.004)
Cattle per woman (1849)			0.009	-0.064	-0.051
			(0.070)	(0.069)	(0.071)
Latitude in rad x 100				3.507***	3.468***
				(0.859)	(0.867)
Longitude in rad x 100				-0.843***	-0.793***
				(0.303)	(0.300)
Women in industry per capita (1867)					-3.397**
					(1.456)
Constant	2.709***	2.620***	2.617***	-0.347	-0.317
	(0.236)	(0.228)	(0.224)	(0.854)	(0.858)
Control variables	Yes	Yes	Yes	Yes	Yes
Observations	334	334	334	334	334
R-squared	0.451	0.472	0.472	0.509	0.509

Note: Robust standard errors in parenthesis. *** p<0.01, ** p<0.05, * p<0.10. Child-woman ratio is the number of children aged 10-19 over the number of women aged 40-69. Female enrolment rate is the ratio of girls enrolled in primary and middle schools over the number of girls aged 6-14. Age at marriage is defined as the share of women who married at age older than 30. Net migration is computed as the difference between immigrants and emigrants over the reference population (*1000).
Source: Own estimates.

Table 4: The effect of mothers' education on fertility—IV (1849 borders)

Dependent variable:	*Child-woman (1867) (OLS)*	*Fem enrolment (1816) (1st stage)*	*Child-woman (1867) (2nd stage)*
Female enrolment rate (1816)	-0.325***		-0.850**
	(0.082)		(0.377)
Landownership inequality (1816-49)		-2.583***	
		(0.561)	
Child-woman ratio (1816)	0.285	-0.108	0.225
	(0.272)	(0.104)	(0.224)
Age at marriage (1849)	-1.394***	-0.038	-1.394***
	(0.228)	(0.178)	(0.225)
Employed in textile factories (1849)	-0.143*	-0.028	-0.142*
	(0.079)	(0.036)	(0.074)
Enrolment rate (1864)	-0.678***	0.851***	-0.186
	(0.167)	(0.116)	(0.390)
Constant	2.307***	0.411**	2.483***
	(0.376)	(0.195)	(0.362)
Control variables	Yes	Yes	Yes
Observations	334	334	334
R-squared	0.466	0.482	0.370
F-Statistic 1st stage			21.180

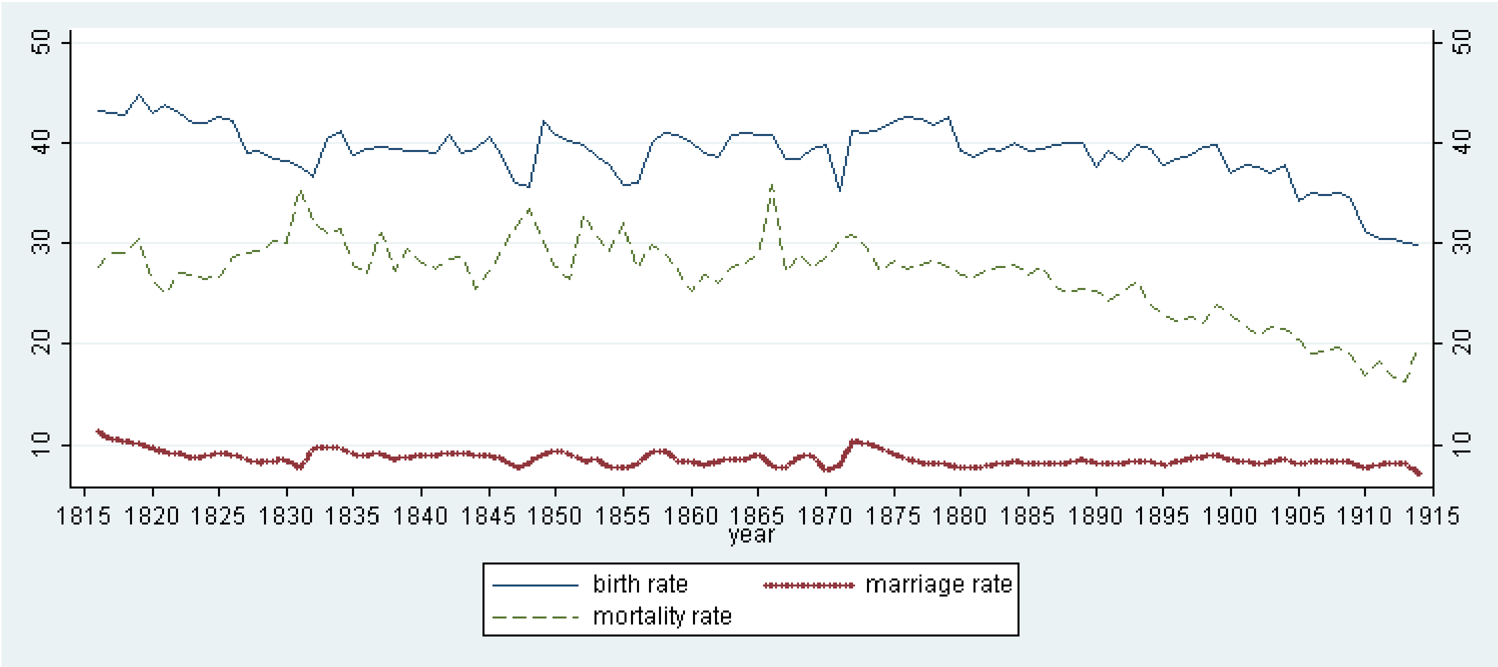
Note: Robust standard errors in parenthesis. *** p<0.01, ** p<0.05, * p<0.10. Child-woman ratio is the number of children aged 10-19 over the number of women aged 40-69. Female enrolment rate is the ratio of girls enrolled in primary and middle schools over the number of girls aged 6-14. Age at marriage is defined as the share of women who married at age older than 30. About landownership inequality see text.
Source: Own estimates.

Table 5: The effect of mothers' education on fertility—IV (1816 borders)

Dependent variable:	*Child-woman (1867) (OLS)*	*Fem enrolment (1816) (1st stage)*	*Child-woman (1867) (2nd stage)*
Female enrolment rate (1816)	-0.379***		-0.665**
	(0.076)		(0.339)
Landownership inequality (1816)		-2.886***	
		(0.621)	
Child-woman ratio (1816)	-0.015	0.004	-0.013
	(0.025)	(0.013)	(0.021)
Age at marriage (1849)	-1.529***	-0.115	-1.556***
	(0.218)	(0.185)	(0.213)
Employed in textile factories (1849)	-0.147*	-0.049	-0.150*
	(0.084)	(0.035)	(0.080)
Enrolment rate (1864)	-0.781***	0.789***	-0.510
	(0.210)	(0.136)	(0.389)
Constant	3.026***	0.403**	3.105***
	(0.251)	(0.166)	(0.259)
Control variables	Yes	Yes	Yes
Observations	267	267	267
R-squared	0.408	0.465	0.377
F-Statistic 1st stage			21.577

Note: Robust standard errors in parenthesis. *** p<0.01, ** p<0.05, * p<0.10. Child-woman ratio is the number of children aged 10-19 over the number of women aged 40-69. Female enrolment rate is the ratio of girls enrolled in primary and middle schools over the number of girls aged 6-14. Age at marriage is defined as the share of women who married at age older than 30. About landownership inequality see text.
Source: Own estimates.

Figure 1: Demographic patterns in Prussia, 1815-1895

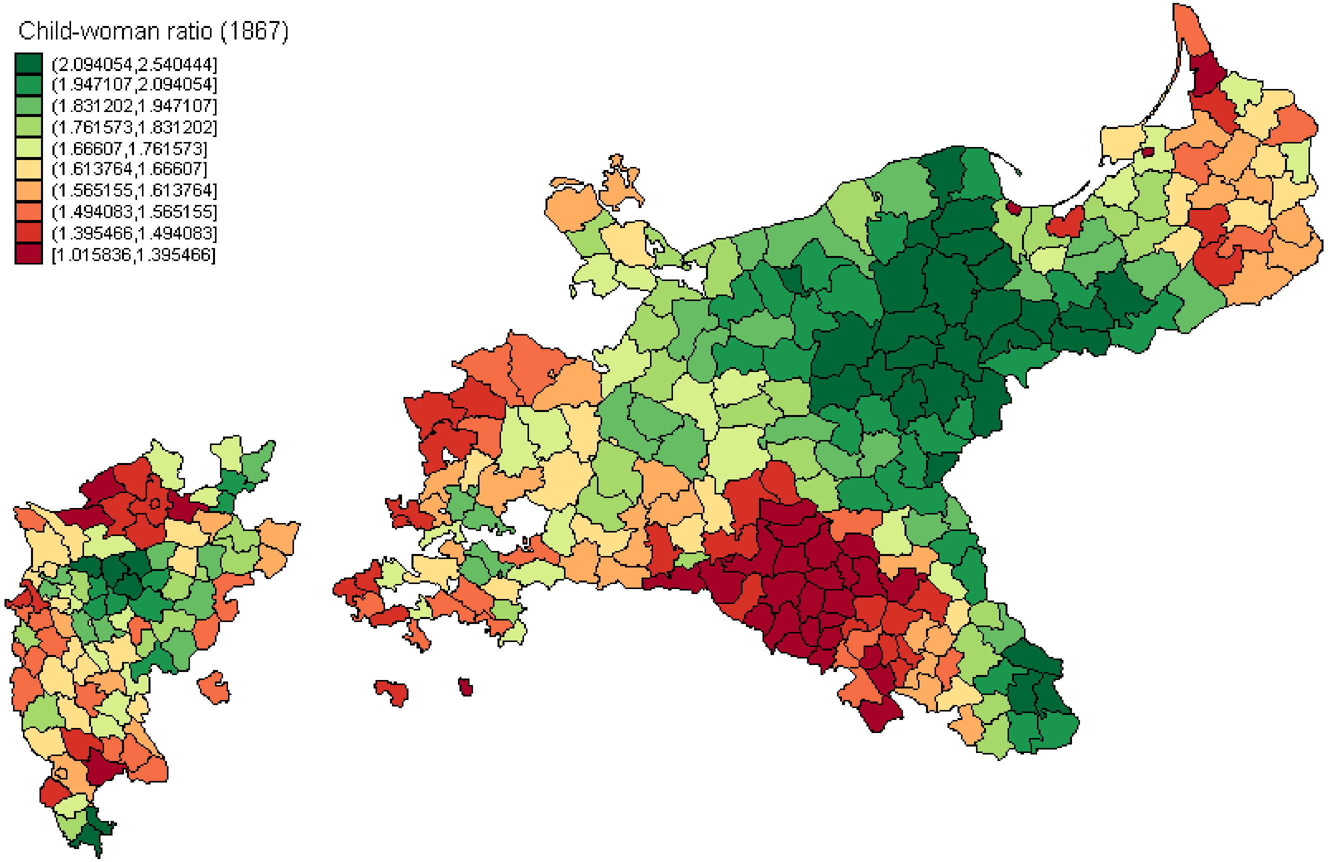


Source: Köllmann (1980); Galloway, Hammel, and Lee (1994)

Figure 2: The relationship between mothers' education and fertility

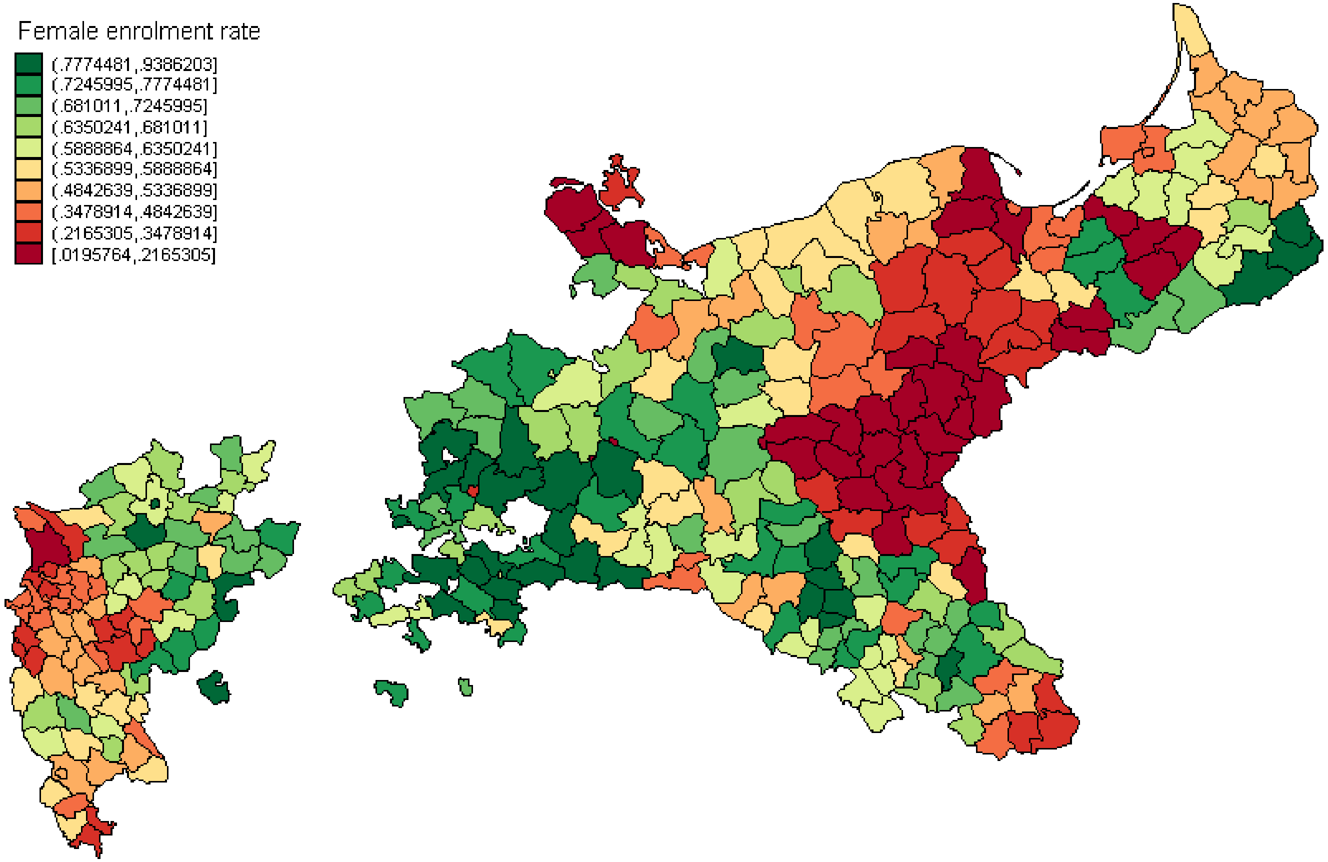
Note: Female enrolment rate is the ratio of girls enrolled in primary and middle schools over the number of girls aged 6-14. The child-woman ratio is defined as the number of children 10-19 over women aged 40-69.

Figure 3: Child-woman ratio (1867)



Note: The child-woman ratio is defined as the number of children 10-19 over women aged 40-69.

Figure 4: Female enrolment rate (1816)



Note: Female enrolment rate is the ratio of female children enrolled in primary and middle schools over the number of girls aged 6-14.