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Did Gender-Bias Matter in the Quantity-Quality Trade-off in 19th Century France?[1]

Claude Diebolt, Tapas Mishra and Faustine Perrin[2]

Abstract

Recent theoretical developments of growth models, especially on unified theories of growth, suggest that the child quantity-quality trade-off has been a central element of the transition from Malthusian stagnation to sustained growth. Using an original census-based dataset, this paper explores the role of gender on the trade-off between education and fertility across 86 French counties during the nineteenth century, as an empirical extension of Diebolt-Perrin (2013). We first test the existence of the child quantity-quality trade-off in 1851. Second, we explore the long-run effect of education on fertility from a gendered approach. Two important results emerge: (i) significant and negative association between education and fertility is found, and (ii) such a relationship is non-unique over the distribution of education/fertility. While our results suggest the existence of a negative and significant effect of the female endowments in human capital on the fertility transition, the effects of negative endowment almost disappear at low level of fertility.

Keywords: Cliometrics • Education • Fertility • Demographic Transition • Unified growth theory • Nineteenth century France

JEL Codes: C22, C26, C32, C36, C81, C82, I20, J13, N01, N33.

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1. Introduction

The child quantity-quality trade-off has been historically hailed as the main motivator of the celebrated transition from Malthusian stagnation to sustained economic growth of recent times. The latter hypothesis has found both considerable theoretical attention – especially in unified growth theoretic tradition (following Galor and Weil, 1999; Galor, 2005), and vigorous empirical analyses (see Diebolt and Perrin, 2013b for a review of literature) over the past decades. Led by unified growth theoretic tradition, while recent empirical research has pointed at the capital importance of human capital dynamics for facilitating the transition from stagnation to sustained growth, an important question that remained largely neglected is the contribution of gender-bias (especially female empowerment) in quantity-quality trade-off. The main purpose of the current paper is to contribute to this important aspect of the burgeoning literature by using *(i)* a unique census-based historical data for 86 French counties for which we have data for the middle of the 19th century as well as for the turn of the 20th century, and *(ii)* by employing the recent development in quantile regression literature to account for full distributional effects of changes in educational status of (male and female) on fertility transition.

During the past two centuries, the Western world has witnessed dramatic economic, demographic and cultural upheavals. This period marked a turning point in historical economic and demographic trends. Western countries experienced similar patterns of economic and demographic transition, despite some variations in terms of timing and speed of changes (Galor, 2012). Before the Industrial Revolution, all societies were characterized by a very long period of stagnation in per capita income with high fertility rates. Since this fateful period, Western countries observed a complete reversal with high sustained income per capita and low fertility (Becker *et al*., 2012; Klemp, 2012). In parallel to economic and demographic transitions, we note profound changes in the structure of the population: formal education became accessible to a vast majority of the population while drastic changes occurred in gender relations.

Empirical regularities raise numerous questions about the potential interaction between demographic transition and economic development in the transition from the epoch of Malthusian stagnation to the Modern Growth Regime. In particular, what can explain the dramatic reversal of the relationship between output growth and population? What are the underlying behavioral forces behind the demographic transition? What are the endogenous interactions between education and fertility that result in the transition phase?

Despite a renewed interest in recent years, empirical evidence of the existence of a parental trade-off between the quantity and the quality of children is still scarce and controversial. As pointed out by Becker *et al.* (2010, 2012), most investigations of the quantity-quality trade-off are based on modern data (such as Rosenzweig and Wolpin (1980), Cáceres-Delpiano (2006), Black *et al*. (2005), Angrist *et al*. (2010) or Li, Zhang and Zhu

(2008) for contemporary analysis). Historical analyses have recently been addressed by Becker *et al.* (2010, 2012), Klemp and Weisdorf (2011) and Fernihough (2011) respectively for Prussia, England and Ireland. Moreover, despite the existence of sporadic research on the existence of any causality between quantity and quality of children, neither modern nor historical antecedents exist that might answer an important question: Does the quantity-quality trade-off (if there is any) exhibit monotonicity over the distribution of the dependent variable or it is just an empirical artefact of only one point of the distribution. For apparent theoretical and policy reasons, heterogeneity in the existence of such a relationship over the entire distribution of education or fertility may have varied implications, which thus far have not been investigated in the literature. Given the veritable importance of this aspect of modelling, this paper will model the interaction between investment in education and fertility using a heterogeneous distribution approach, viz., quantile regression approach.

Ours will be an investigation from a historical perspective. In particular, using a census-based dataset of 86 French counties built from the *Statistique Générale de la France* (1851, 1861, 1867, 1881, 1911 records and censuses), we empirically investigate: *(i)* whether a child quantity-quality trade-off existed in France in the 19th century; and *(ii)* whether and to what proportion male and female endowment in human capital affected fertility. This paper is the first attempt to test the existence of a quantity-quality trade-off using French data.

France is an iconic case, particularly interesting to investigate. While France was the most populated European country at the dawn of the nineteenth century, it is the first country to experience the fertility transition in Europe. The French demographic transition can be clearly divided in two clear phases. Before 1851, fertility transition is a rural phenomenon, rapid in its infancy and driven by prosperous departments (Van de Walle, 1986). After 1851, the process slows down and fertility even increases slightly for almost half departments. During the last quarter century, France experiences a resurgence of its demographic transition at the same time of the beginning process in most European countries. In the 19th century France was also a precursor in the light of primary education. In 1792, Condorcet already proposed a reform for secular, compulsory and free schooling. Since 1833, the Guizot law has required municipalities with more than 500 residents to fund a primary school and a teacher. An even more fundamental progress is the repeal of the Ferry laws establishing free (1881), secular and compulsory (1882) primary school.[3] Recent research, such as Frank and Galor (2015) also use the specific case of France to examine how industrialization (via the effect on human capital formation) triggered a fertility decline.

Similar to existing studies, our empirical analysis also focuses on the link between education and fertility choices. However, the central point of departure from the extant work and ours is to explore the role of gender-bias in human capital formation leading to fertility choice and thus contributing to the quantity-quality trade-off. We first start by investigating the existence of the trade-off in 1851 France using simultaneous

[3] These laws are seen as a consequence of the 1870 war against Prussia – German soldiers being judged better educated than the French one.

quantile regression framework – which is known to allow significant heterogeneity in the slope estimates over the distribution of the dependent variable. Possible endogeneity bias is corrected by employing an instrumental variable quantile regression approach for both education and fertility equations. Our results show evidence of a significant interaction between quantity and quality of children in 19th century France. Second, based on the same method, we test the impact of the accumulation of maternal and paternal human capital in the middle of the 19th century on the fertility transition at the turn of the 20th century. We find that the fertility transition in France was significantly more pronounced in counties with higher female endowment in human capital. Hence, our findings of a negative relationship between female human capital and fertility are consistent with the unified cliometric growth model of Diebolt and Perrin (2013b) – in which the transition from stagnation to sustained growth is brought about by a gradual change in the female bargaining power within the household.

The rest of the paper is structured as follows. Section 1 introduces the theoretical background and places our contribution within the existing literature. Section 2 provides an annotated description of our dataset by presenting main conclusions from the descriptive statistics and distributional characteristics. Section 3 presents the methodological setting where we provide both empirical construct drawn from theory and estimation method concerning quantile regression approach. Empirical results on the existence of a quantity-quality trade-off in 1851 France are discussed in Section 4. In this section, we also discuss the validity of the hypothesis that female empowerment played a key role in the process of demographic transition. Finally, Section 5 concludes by summarizing the main findings of the paper.

2. Theoretical Background and Related Literature

2.1 Theoretical Illustration and Testable Predictions

First advanced by Galor and Weil (1999, 2000),[4] unified theories of growth model the transition from Malthusian stagnation to modern economic growth in a single framework. Common to most unified models, the emergence of new technologies during the process of industrialization increased the need for skilled workers (i.e. the demand for human capital) and induced parents to invest more in the education of their offspring. Investing in education increases the opportunity cost of having children and implies for parents to choose between number and education of children. This process in turn triggered a shift from high fertility to greater education of children which led to the demographic transition. This is the so-called child quantity-quality trade-off.[5] Since the seminal work of Galor and Weil (1999, 2000) and Galor and Moav (2002), the role of human capital has been largely recognized as crucial in the movement toward developed economies. In

[4] The seminal work of Galor and Weil was quickly followed by new contributions (for an overview see Diebolt and Perrin, 2013b).
[5] Becker (1960) was the first to introduce the distinction between child quantity and child quality, followed by Becker and Lewis (1973) and Willis (1973).

most unified growth model, the child quantity-quality trade-off is considered as a key mechanism allowing economies to switch from a positive correlation linking income and population size, during the Malthusian stagnation, to a negative one, during the modern growth regime.

In this line of research, Diebolt and Perrin (2013b) bring to light new determinants of the long transition process. Their work incorporates novel and additional mechanisms consistent with observed stylized facts, emphasizing the importance of the role played by women in the development process. The main concern of their study is precisely to show to what extent and through which mechanisms gender equality affects decisions taken by members of the household and acts on long run economic development. Through the construction of a cliometric unified growth model, they capture the interplay between fertility, technology and income per capita in the transition from stagnation to sustained growth. The theory suggests that female empowerment has been at the origin of the demographic transition and engaged the take-off to Modern economic growth. At the dynamical level, the increase in gender equality and the rise in technological progress create higher opportunities for women to invest in skilled human capital. The negative correlation linking maternal investments in human capital and fertility (career or family – Goldin, 2006) encourages families to have fewer children but better educated ones. This process ultimately triggers to the demographic transition and plays a central role for the transition from stagnation to modern growth. The model therefore generates documented facts about epochs of stagnation, characterized by high fertility and low output, and modern growth, combining low fertility and sustained output growth.

Using the framework of Diebolt and Perrin (2013b), the quantity-quality trade-off can be characterized by the following simplified model. We consider a two-sex household that generates utility from the male consumption, c^m, the female consumption, c^f, and from the lifetime income of their children, yn – which results from supplying human capital on a competitive labor market. The parameter θ represents the female bargaining power in the household decision process[6]. A fraction θ of income is spent by the woman on consumption. The remaining fraction $(1-\theta)$ is spent by the man income on consumption. The parameter γ measures the value attached to the number of offspring relative to the labor force participation. The household preferences are represented by the following utility function:

$$U\left(c^m, c^f, yn\right) = (1-\theta) lnc^m + \theta lnc^f + \gamma ln(yn) \qquad \text{with} \qquad \theta, \gamma \in (0,1) \tag{1}$$

Each member of the household is endowed with one unit of time. The women spend a fraction of her time r^f (with $r^f > r^m = 0$) rearing children. The price of a child is the opportunity cost associated with raising it, $rnwh^f$. Individual's quality is conditional to its endowment in human capital that depends positively on

[6] The female bargaining power is assumed to be function of the relative stock of human capital of the spouses and can be interpreted as a measure of gender equality within the household.

maternal endowment in human capital, $\hbar^f$, and on one's own investment in education e. The household lifetime budget constraint is therefore:

$$c^m + c^f \leq \left(1 - rn - e^f\right)wh^f + (1 - e^m)wh^m \tag{2}$$

The optimization problem yields to the following first order conditions on education,

$$e^m = \frac{1 + \underline{e}}{2} \tag{3}$$

$$e^f = \frac{\left(1 + \underline{e} - rn\right)}{2} \tag{4}$$

where $\underline{e}$ is a fix cost of education measured in time units that agents have to pay when investing in education.

Everything else being equal, equation (4) depicts a trade-off between female investment in education and fertility. The optimal number of children is decreasing with the time invested by the woman in her education. Consequently, the acquisition of skilled human capital induces women to spend more time on education and to have fewer children.

The household optimal fertility is given by:

$$n^* = \frac{\left(1 - \underline{e}\right)}{r\theta} \frac{\gamma}{(2 + \gamma)} \tag{5}$$

The optimal fertility level is decreasing with the female marital bargaining power within the household. A higher level of gender equality within the household allows women to reduce their fertility and to invest more in education. Hence, women have fewer children but better educated ones. Ultimately, equations (4) and (5) show a trade-off between the number of children and their quality. The quantity-quality trade-off implies the optimal number of children to be decreasing with the time invested in each of them.

Thus, the theory generates two main testable implications:

(1) The existence of a child quantity-quality trade-off[7]

- The optimal number of children declines if the cost of raising a child increases
- The level of child quality increases when the cost of raising a child increases

[7] An increase in the relative price of the quantity of children decreases the number of children and increases the investment in each child.

(2) The existence of a female trade-off between educational investment and fertility[8]

- The level of fertility is inversely proportional to the level of female investments in education
- The female accumulation of human capital triggers a fertility transition

2.2 Related literature

Despite the key role played by the quantity-quality trade-off in the unified growth literature, empirical investigations of the links between fertility and education remain scarce. Two types of studies have emerged: the studies investigating the effect of fertility on education and the studies investigating the effect of education on fertility. Most of these studies are based on modern data. This is the case of the work done by Rosenzweig and Wolpin (1980), Cáceres-Delpiano (2006), Black *et al.* (2005), Li *et al.* (2008) or Angrist *et al.* (2010) for more contemporaneous studies. Analyses based on past data have however been recently addressed. Hence, Becker *et al.* (2010, 2012) have investigated the relation using Prussian data while Klemp and Weisdorf (2011) studied the English case and Fernihough (2011) the Irish one.

Some authors have chosen to investigate the effect of fertility on education. The first study investigating the fertility effect on education is Rosenzweig and Wolpin (1980). Using an IV strategy with modern data, they found evidence supporting the existence of a quantity-quality trade-off among Indian households. Hanushek (1992) finds a distinct trade-off between quantity and quality of children, using individual level data within 1971 and 1975 in Iowa. Considering the allocation of time to children, he finds that achievement falls systematically with increased family size. Using multiple births Black *et al.* (2005) corroborate this effect from fertility to education based on a dataset on the entire population of Norway. Angrist *et al.* (2010) however find no evidence of a quantity-quality trade-off for Israeli. Several studies have investigated this relationship using Chinese data and have found contradictory results. Estimating the effect of family size on school attainment using multiple births and variation in China's one-child policy, Qian (2009) find a positive effect of the increase in family size on the child enrollment rate. Conversely, Rosenzweig and Zhang (2009) show that having extra-child decreases significantly endowment in human capital of all children in the family. Based on individual level data from 15 Anglican parishes within the period 1700-1830, Klemp and Weisdorf (2011) examine the existence of the child quantity-quality trade-off for historical England. Using time interval from marriage to first birth (number of siblings who survive to age five) as a measure of exogenous variation in family size, they find a negative causal effect of family size on individual literacy. Using a sample of individual level data from 1911 Census of Ireland, Fernihough (2011) investigates the impact of sibling size on school enrollment in Belfast and Dublin. He finds strong evidence of a negative impact of extra sibling on school enrollment. He also finds that the quantity-quality mechanism is stronger in more industrialized areas.

[8] According to the theory, this trade-off (based on women anticipations) is at the origin of the child quantity-quality trade-off.

Other authors have however chosen to analyze the opposite direction of causation, from education to fertility. Galloway, Hammel and Lee (1994) show a negative effect of educational variables on the marital fertility rate for Prussia. Similarly, Dribe (2009) find that variations in the levels of education are relevant for explaining fertility decline in Sweden for the period 1880-1930. From micro data in 1970s Indonesia, Breierova and Duflo (2004) estimate the effect of education on fertility and child mortality. On the one hand, they show that parental education has a strong causal effect on the reduction of child mortality. They also find that female education seems to matter more on female age at marriage and on early fertility rather than does male education. Similarly, Osili and Long (2008) estimate the exogenous effect of female education on fertility (by age 25) in 1970s Nigeria. They conclude that the establishment of an educational program increased female schooling and decreased fertility. Bleakley and Lange (2009) show the consistency of the quantity-quality trade-off and unified growth theory in the case of Southern USA. They argue that the eradication of hookworm disease reduced the cost of child quality increased education and decreased fertility. Murphy (2015) examines the potential factors driving the fertility decline within France during the fertility transition. Using panel fixed-effects, he finds that more education (measured by the literacy rates) is negatively correlated with fertility[9].

Only Becker *et al.* (2010) investigate both direction of causality. Based on aggregated regional data for 19th century Prussia, they find evidence of a causal relation between education and fertility, consistent with the quantity-quality trade-off. More recently, Becker *et al.* (2013) show that increases in women's education played a role in reducing fertility in 19th century Prussia, already before the demographic transition.

3. A French County-Level Database on Education and Fertility

3.1 Source and Measurement

In this paper, we address the quantity-quality trade-offs in historical perspective using French county-level data. We consider both the short-run and the long-run nexus between education and fertility. First, we investigate the two directions of causality between child quantity and child quality in 1851 in France. Second, we study the long-run impact of the accumulation of human capital on the demographic transition during the 19th century. Our incentive is to check whether parental investment in education has an effect on the ability of their children to succeed in education (process driving to the accumulation of human capital). To do so, we use county-level data collected from diverse publications of the *Service de la Statistique Générale de la France*. Our dataset covers information about aggregated individual-level behavior for 86 French counties (*départements*).[10] The French Statistical Office publishes data from 1800 but it is from 1851 only that it

[9] This result is not found when the author uses the pooled OLS analysis.
[10] 1851 France consists of current metropolitan French *départements* except Alpes-Maritimes, Savoie and Haute-Savoie.

published data ranking the population by age, gender, marital status and providing other essential information to study the evolution of fertility behavior and habits regarding education.

The major part of the dataset is constructed from General Censuses, Statistics of Primary Education, Population Movement and Industrial Statistics conducted in 1851 (1850 for Education, 1861 for Industrial Statistics). The rest of the data stems from diverse sources. A part of fertility data is available from the Princeton European Fertility Project (Coale and Watkins, 1986). Data on life expectancy at birth come from Bonneuil (1997). A combined use of the various Censuses allows us to construct a dataset with detailed information on fertility, mortality, literacy rates, and enrollment rates in primary schools for both boys and girls, employment in industry and agriculture by gender, level of urbanization and stage of industrialization. In addition, we use data from French Censuses for the years 1821, 1835, 1861, 1881 and 1911 to get more demographic and socio-economic information necessary to carry out our analysis.[11]

In the *short-run* analysis, we use the crude birth rate as a measure of fertility behavior, defined as the number of birth per thousand people. The reason for using CBR is that it is well-suited to construction from vital registration and census data. Moreover, it is easy to calculate when using historical data. For robustness analysis, we have used General Fertility Rate which is measured as the number of births per women in age of childbearing (15-49). There are of course alternative measures of fertility suggested in the literature, for instance, index of marital fertility (used in Murphy, 2015, and Frank and Galor, 2015). However, this measure inherits some important limitations; Sanches-Barricarte (2001) argue that this indicates is not a good indicator when there is important delay in female mean age at marriage. Indeed, this was the case for several counties in France in the middle of the 19th century (see Perrin, 2013, p.52). This leads us to choose a simple measure, CBR, which is frequently used and suffer less from these misspecification biases.

To measure education, we use enrollment rates in public primary school in 1850, constructed as the number of girls (boys) attending school divided by the total number of girls (boys) aged 6-14. The main specifications applied in our analysis are expected to capture: *(i)* the variations in fertility with educational level and in education with fertility level; and *(ii)* the supply and demand factors represented by a set of control variables. The supply and demand factors aim at capturing both economic and cultural factors likely to have impacted educational and fertility behaviors. The demand for children, for instance, depends on the opportunity cost of having children. Based on the prediction of theoretical models, we expect income to affect fertility. As a proxy for the income level, we use the urbanization level, the population density, as well as the employment opportunities, measured by the share of women (men) employed in manufacturing and in agriculture. As a control for the supply of children, we use the life expectancy at birth. The life expectancy at birth allows controlling for the decline in infant mortality and may be a proxy for the lengthening of both the individual

[11] To our knowledge, these data have not yet been used for micro-econometric analysis.

longevity and the reproductive period. We also control for religion in order to account for cultural differences that may have affected individuals' behaviors in regards with fertility (birth control) and education (Lutheran ideas). As a measure a religious practices, we use the share of Protestants within the population.

For the *long-run* analysis, we use literacy rates to capture the amount of human capital accumulated. One limitation (already raised by Becker *et al.*, 2010) of using enrollment rate in education relates to the fact that attendance at the census date might not be the same as year-round attendance what prevent from capturing the amount of human capital accumulated. We use similar control variables to the one used in the short-run analysis. Hence, we control for the level of urbanization, employment opportunities, and religious practices. As additional controls, we use the crude birth rate in 1851 in order to address potential issues raised by intergenerational correlation of fertility. In order to account for differential fertility development that might have occurred before the fertility transition, investigated over the period 1881-1911, we control for the initial level of fertility in 1881, measured by the crude birth rate.

3.2 The Data – France in the 19th Century

The analysis of transversal and longitudinal data from France, ranging as far back as the mid-eighteenth century, uncovered key socio-economic, demographic, geographic, and cultural patterns that have marked a turning point in the French economic history.

(i) Historical Background

Fertility. – The study of long-run demographic trends puts into perspective several important findings about the French fertility transition. France, as other Western countries, experienced major demographic changes over the past two centuries (decline in mortality, increase in population, decline in fertility, expansion of life expectancy at birth, etc.). However, France is iconic by the timing of its fertility transition. While France was the most populated European country at the dawn of the 19th century (what accounted for its superiority in previous centuries), it entered at that same moment into a fertility transition, almost a century prior to other European countries (Chesnais, 1992). Despite an overall increase in the availability of resources, the number of offspring radically declined. The French demographic transition can be clearly divided into two phases. In the first phase, before 1851, this was a rural phenomenon, rapid in its infancy and driven by prosperous departments (Van de Walle, 1986). In the second phase, from 1851, the process of demographic transition slowed down and fertility even increased slightly for almost half of the departments. France experienced a resurgence of its demographic transition during the final quarter of the 19th century.

Education. – The investigation of educational investments shows strong differences between boys and girls. Over the 19th century, women were on average less trained than men. Women opportunities and access to education were limited and bounded. Additional education was often limited to specific knowledge related to housework and skills required for their future role within the household as mother and wife. The 19th century marked however deep improvements in individuals' endowments in human capital. Formal education became accessible to a vast majority of the population. While a huge share of the population was illiterate in the early 19th century, only a small fraction of the population remained unable to read and write at the turn of the 20th century. The feminization of education notably through the implementation of laws and decrees (Pelet 1836, Duruy 1867, Sée 1879 or Bert 1879) encouraging the development of infrastructures allowed girls to fill a large part of their delay in schooling. Female literacy rates caught-up male rates at the turn of the 20th century. Educational investments diffused across the French departments throughout the 19th century from the most industrialized areas of France to the dominantly agrarian part of the country. The massive and widespread access to education occurred gradually from primary education to secondary education and later in time (during the 20th century) from secondary education to tertiary education. Women became more and more trained. Long-run trends reveal strong improvements in the quality of the labor force that reversed in favor of women by the early 20th century (see Perrin, 2013).

Labor Force. – The exploration of the evolution of the labor market and workforce provides hints to improve our understanding of changes in fertility behaviors and educational investments. The study of the evolution of the labor force participation reveals that the female labor force in paid activities increased substantially over time both in numbers and in its structure. Economic development led to strong upheaval in the social structure of the workforce. The rural exodus drove agricultural workers to cities; a decline in the peasantry (craftsmen and tradespeople) occurred slowly in favor of manufacturing workers during the 19th century. In the North of France, women entered the labor market, mainly via the development of textile industries. Women working in industry were usually young and single. However, the evolution of the female labor force by marital status (Bairoch, 1968) and age (Marchand and Thélot, 1997) reveals a significant increase in the share of married women and women in childbearing age in the labor force. At the same time, the share of women aged 15-24 in the labor force experienced an important decline. The variations of the female labor force suggest an evolution of gender relations on the labor market.

Culture. – The intensity of religious practices helps understanding the geographical distribution and regional dynamics of fertility and education. While the counties characterized by larger share of Catholic and Protestant were using the Malthusian regulation (fertility control through marriage), secular areas were more likely to use the control of births within marriage. Similarly, Protestantism had a peculiar relationship with education. Luther emphasized the importance of education and the need of a strong classical culture and required the establishment of schools for the children of ordinary folks. The evolution of literacy rates and schooling in France seems to have spread first from the Northeast border and then from the whole East border (Perrin, 2013) – strangely reminiscent of the spread in circle of Lutheran ideas around Wittenberg as put forward for Prussia (Becker and Woessmann, 2009).

France during the 19th century was subject to profound transformations with regards to demographic behaviors, educational investments or structure and involvement in the labor market. The French regional landscape changed significantly, at a faster pace for some counties than for others. This overview suggests the existence of intricate relationships between education, fertility, industrialization and cultural factors in France during the development process.

(i) Descriptive statistics

Table 1 reports descriptive statistics of the variable used in our analysis. In general, the statistics evince heterogeneity in our variables across counties and over time. In 1850, 54.5% of boys aged 6-14 were enrolled in public primary school, while the enrollment rate in public primary school for girls was 36%. Some counties dedicated important effort on educational investments for boys but also for girls, i.e. counties located in the northeastern diagonal part of France. Enrollment rates spread from 19% to 106% for boys and from 0.3% to 99% for girls in 1850.[12] The period 1850-1867 recorded fast changes. The number of counties with girls' enrollment rates higher than 50% expanded significantly. This fast increase was followed by a consolidation period, between 1867 and 1876 during which national enrollment rates increased from 66% to 72.3%. The increase in schooling between 1867 and later periods occurred mainly through the catch up of counties which were originally lagging behind. In 1881, 70.84% of boys and 57.16% of girls (aged 5-15) were enrolled in public primary schools.[13] These variations can be explained by several factors: the diffusion of the official French language, the difference in attitudes toward education between Catholics and Protestants (Becker and Woessmann, 2009), the wave of spreading ideas coming from Prussia and the insufficiency of educational resources deployed in rural areas in terms of teachers and financial spending.

Figure 1a and 1b display the geographical distributions of boys and girls enrollment rates in 1850. The maps highlight a development gap between Northeastern-France and Southwestern-France separated by the famous line Saint-Malo/Genève. Similarly to Prussia (see Becker *et al.*, 2010), the most industrialized area (the Northeast part in France) shows higher enrollment rates. These variations may also find explanations in the different attitudes toward education between Catholics and Protestants as advanced earlier and by the insufficiency of educational resources in terms of teachers and financial spending deployed in rural areas.

[12] Enrollment rates above 100% are due to the possibility that children below 6 years old and above 14 years old were enrolled in public primary schools.
[13] This does not appear in the summary statistics but is available in the data.

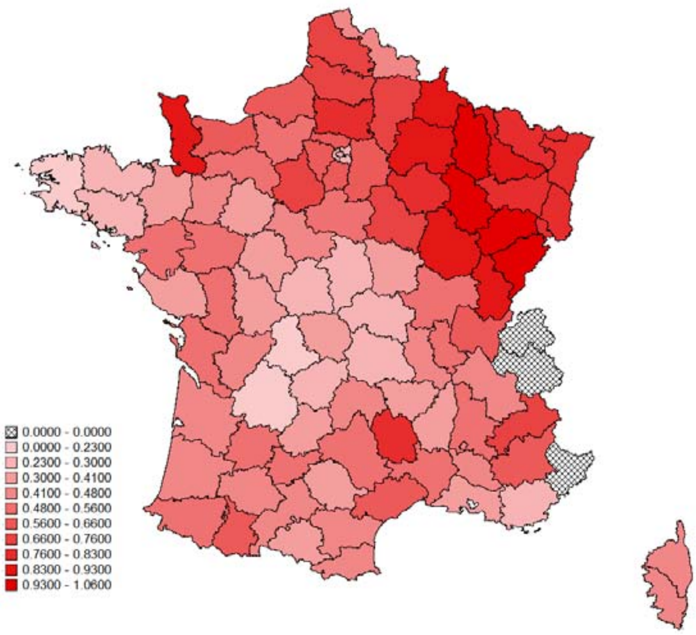
Table 1 – Summary statistics				
	Mean	Std. Dev.	Min	Max
Education				
School enrollment rate (1850)	0.454	0.229	0.13 3	1.029
Boys enrollment rate (1850)	0.544	0.211	0.188	1.059
Girls enrollment rate (1850)	0.356	0.259	0.003	0.997
Boys enrollment (1850-67)	0.600	0.342	-0.076	1.624
Girls enrollment (1850-67)	1.067	1.962	0.017	17.485
Male literacy (1856-70)	0.113	0.092	-0.093	0.358
Female literacy (1856-70)	0.271	0.213	-0.085	0.956
Boys schools (1850)	1.217	0.588	0.143	2.616
Girls schools (1850)	0.152	0.170	0.005	0.907
Distance to Mainz (in km)	699	248	181	1222
Fertility				
Crude birth rate (1851)	26.95	3.597	18.717	34.275
Index of marital fertility rate (1851)	0.497	0.109	0.298	0.747
Crude birth rate (1881)	24.22	3.798	17.28	34.57
Crude birth rate (1881-1911)	-0.245	0.092	-0.405	-0.002
Marital fertility rate (1851)	3.218	0.579	2.07	4.77
Marital fertility rate (1881-1911)	-0.290	0.091	-0.476	0
Economic				
Share in industry (1851)	0.029	0.047	0	0.370
Share in agriculture (1851)	0.426	0.106	0.031	0.655
Male in industry (1851)	0.057	0.081	0	0.636
Male in agriculture (1851)	0.737	0.171	0.046	1.135
Female in industry (1851)	0.036	0.070	0	0.552
Female in agriculture (1851)	0.615	0.179	0.037	1.054
Urbanization (1851)	0.029	0.074	0.003	0.694
Population density (km²) (1851)	1.011	3.166	0.219	29.907
Male wages in agriculture (1852)	1.414	0.287	0.77	2.52
Female wages in agriculture (1852)	0.892	0.186	0.55	1.62
Demographic				
Male life expectancy at age 0 (1856)	38.080	4.424	26.454	48.960
Female life expectancy at age 0 (1856)	40.556	4.834	27.506	49.846
Share married women (1851)	0.534	0.057	0.430	0.641
Male workers (1861)	11 918	19 106	735	141 905
Female workers (1861)	5 271	8 167	215	54 062
Adult sex ratio (1851)	0.993	0.063	0.810	1.194
Infant mortality (1851)	0.301	0.078	0.162	0.483
Child mortality (1851)	0.040	0.012	0.019	0.068
Socio-economic				
Share Protestants (1861)	2.258	5.332	0.003	31.298

Note: Detailed description of variables is provided in appendix

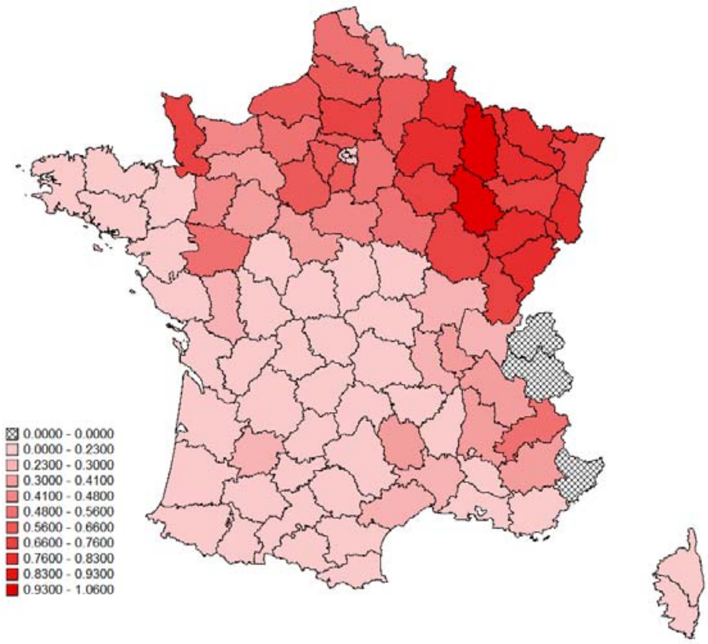
The rural and more agricultural remainder of France displays higher fertility rates in 1851, as evidenced by Figure 1c. Similarly to education, data on fertility show an important heterogeneity across counties. These differences support the evidence that some counties have adapted their fertility behavior and therefore experienced a demographic transition before others.

Figure 1: Geographical Distribution of Education and Fertility

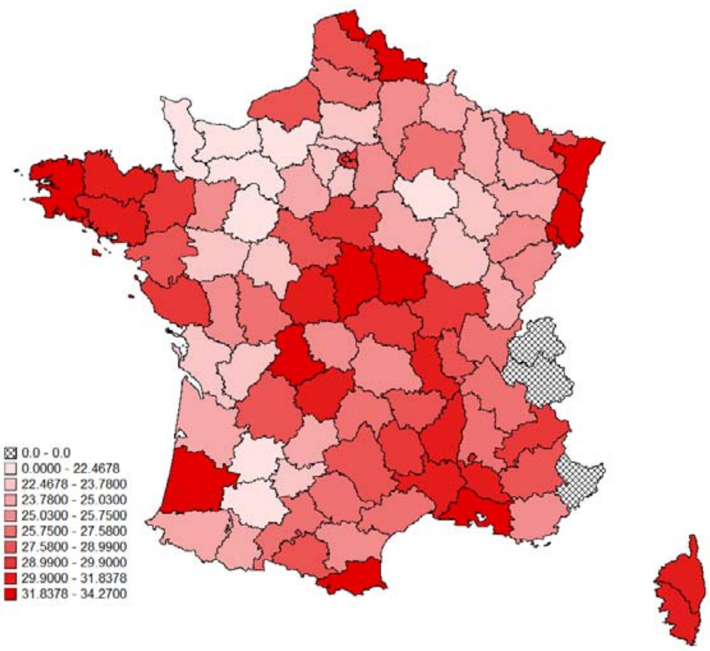
(1a) Boys Enrollment Rate, 1850



(1b) Girls Enrollment Rate, 1850



(1c) Crude Birth Rate, 1851



Sources: Using data from Statistique Générale de la France – Enseignement Primaire 1850; Census 1851

A crude birth rate close to 40 is considered as a natural level of fertility, i.e. the level of fertility that would prevail in a population making no conscious effort to limit, regulate or control fertility (Henry, 1961). According to Chesnais (1992), a crude birth rate below 30 per one thousand individuals marks the entry into a regime of controlled fertility; a crude birth rate below 20 children per one thousand individuals suggests that a large share of the population practice birth control. In 1851, the average crude birth rate was 27‰, ranging from 18.72‰ to 34.27‰. In 1851, 19 counties over 86 exhibited a crude birth rate above 30 children per thousand individuals. Thirty years later, in 1881, the average fertility rate decreased to 24‰, with minimum and maximum crude birth rates equal to 17.28‰ and 34.57‰, respectively. Seven counties only (all located in the periphery of the country) exhibited crude birth rates above 30 children per thousand individuals.

Two opposite profiles emerge from the analysis of socio-economic and demographic characteristics of French counties in the mid-19th century. On the one hand, we find agrarian counties characterized by a poorly educated population and higher fertility rates. On the other hand, we find industrialized, but still rural areas putting significant effort on education for both genders, women tend to be more integrated in the labor market, and fertility rates seems to be lower. The investigation of regional characteristics emphasizes the importance of considering the education-fertility relationship from a gender perspective.

(ii) Distributional Characteristics

We presented above the distributional characteristics of fertility and education to motivate the development of required estimation tool for testing hypotheses on quality-quality trade-off. This subsection presents the density plots of these variables to detect possible multimodality or cluster dynamics in the data.

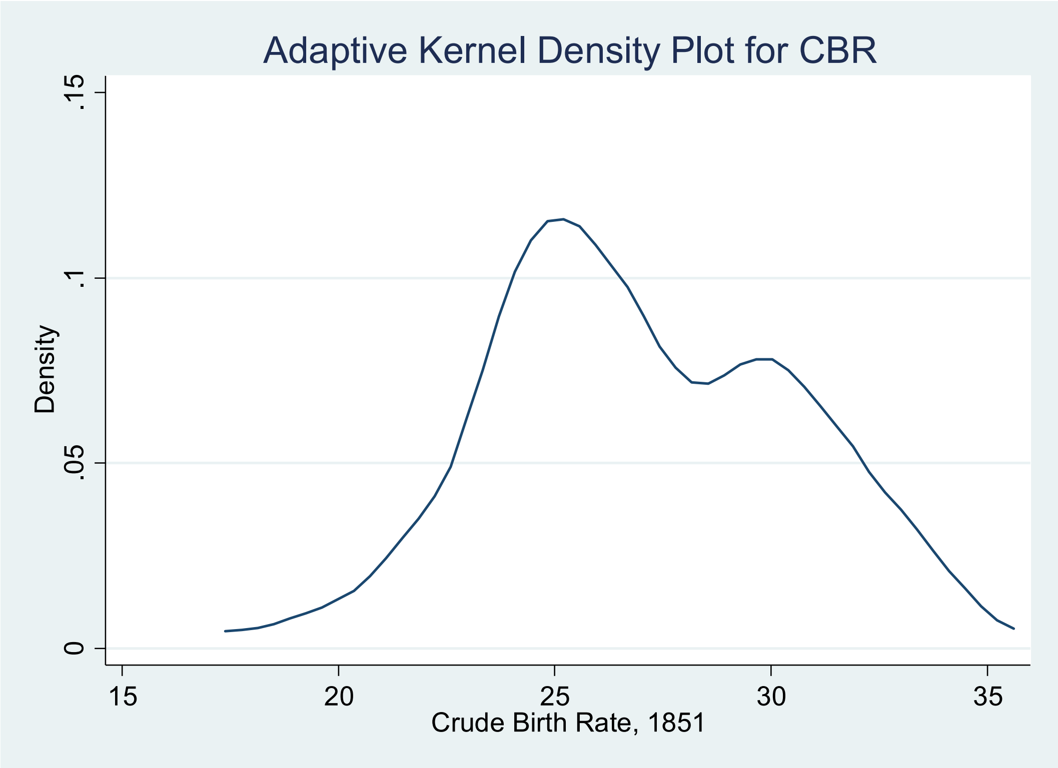
Our next focus is on detecting if the (statistical) distribution of these variables presents any evidence of multimodality. This is important for several reasons; one of them being that such evidence would guide us in choosing the correct estimation method – for instance, whether to focus on the 'mean-based' conventional OLS method or to adopt 'quantile-based' full distributional method. Another leading reason is that any evidence against unimodality of distribution of these variables would indicate possible presence of multiple equilibria/clusters, leading to variable inferences at various points of the distribution the dependent variable. Alternately speaking, it might be possible for instance, that the response of fertility to low educational attainment level is significantly different (both quantitatively and direction of causality-wise) from the one at high educational attainment levels. From theoretical perspective, this makes sense as one would expect the existence of quality-quantity theory primarily at higher educational achievement levels leading to gender equality in education and female empowerment. The choice of fewer children then becomes essentially a reflection of investigation of the relationship at higher quantile of the distribution of the variable. The non-uniqueness of fertility-education trade-off relationship at various quantile of the distribution (instead of just focusing on the mean of the distribution, i.e., OLS) is more informative and would enable us to test the validity and consistency of the theory at various points of the distribution.

Following this idea, we have presented Adaptive Kernel density plots of crude birth rate (Figure 2a.1) and enrollment (Figure 2a.2). It needs mentioning at this point that adaptive Kernel density extends the possibilities offered by Kernel density estimation in two ways: first, it allows the use of varying, rather fixed bandwidth. Second, it provides estimation of pointwise variability bands. Following this density estimation, these two figures present evidence of significant bimodality – which is further confirmed by Hartigan and Hartigan's (1985) Dip test. In case of fertility, the crude birth rate mean is 26.976 with a standard deviation of 3.610. However, Figure 2a.1 present two significant modes (one around 30 years and another at 25 years). These modes, as confirmed by Diptest are significant at 5% level. Likewise, education (enrollment rates) for both men and women also depict significant bimodality (weaker for men – Diptest accepted at 10% level) whereas it is stronger for women (accepted at 5% level).

In Figure 2b.1 and 2b.2 we have presented the bivariate Kernel density plots for CBR and enrollment rate (boys and girls). The contours reflect the fact that low educational attainment for girls evinces higher fertility rate, which is far greater than that of the male with similar enrollment scale. Moreover, we have also performed a skewness test of CBR as well as the enrollment rate for boys and girls. Figure 2c (2c.1 for male enrollment, 2c.2 for female enrollment, and 2c.3 for CBR) present the skewness plots. A rising graph implies that there is significant bias to the right of the distribution and the distribution is not normal. Indeed, all three graphs depict the expected pattern: they are right-skewed distributions and therefore the mean and the mode of these distributions are markedly different. These results and the reasons cited above motivate us to go beyond conventional OLS based estimation method, as the estimated coefficients may be either under- or over-estimated and may not present the complete picture of the response of education to changes in fertility (and the converse). Alternative estimation method, such as quantile regression technique, has been found to be very useful in this regard. We present them in the next section.

Figure 2a: Distributional Characteristics of Fertility and Education

(2a.1) Distribution for crude birth rate



(2a.2) Distribution for enrollment rate

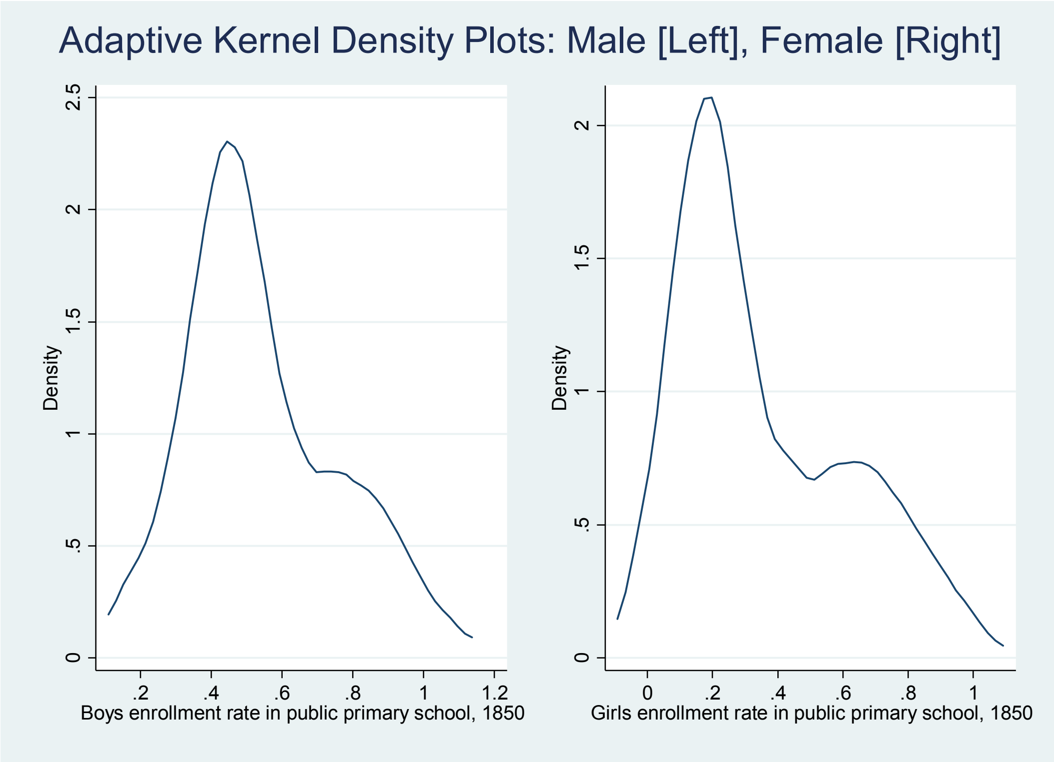


Figure 2b: Bivariate Density Plots for Fertility and Education: Boys and Girls

Figure 2b.1 Boys

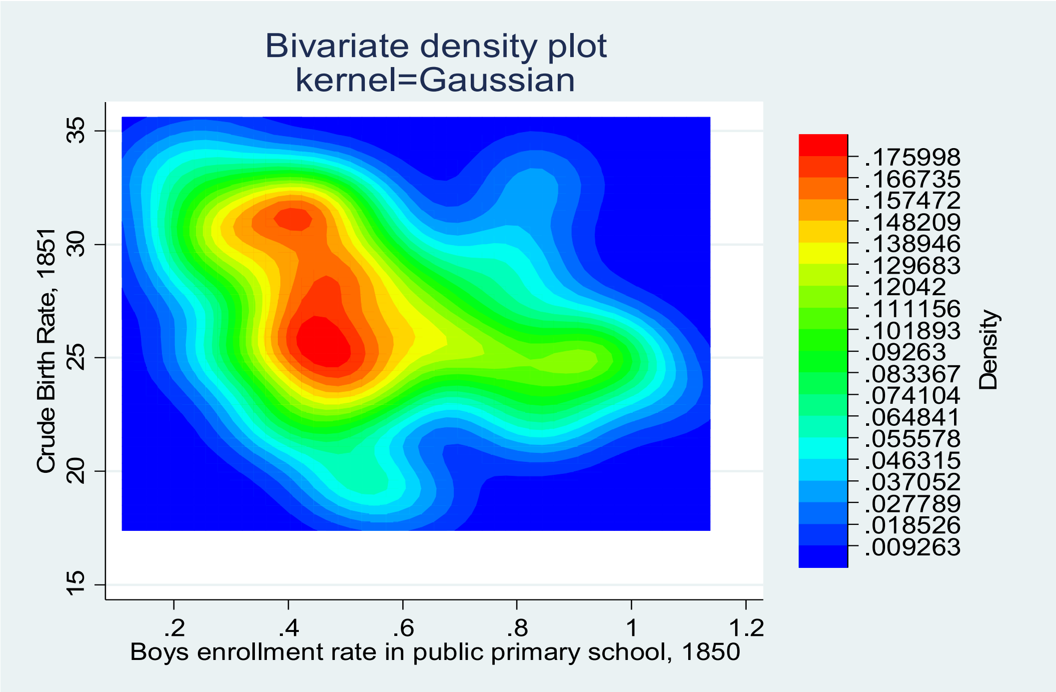


Figure 2b.2 Girls

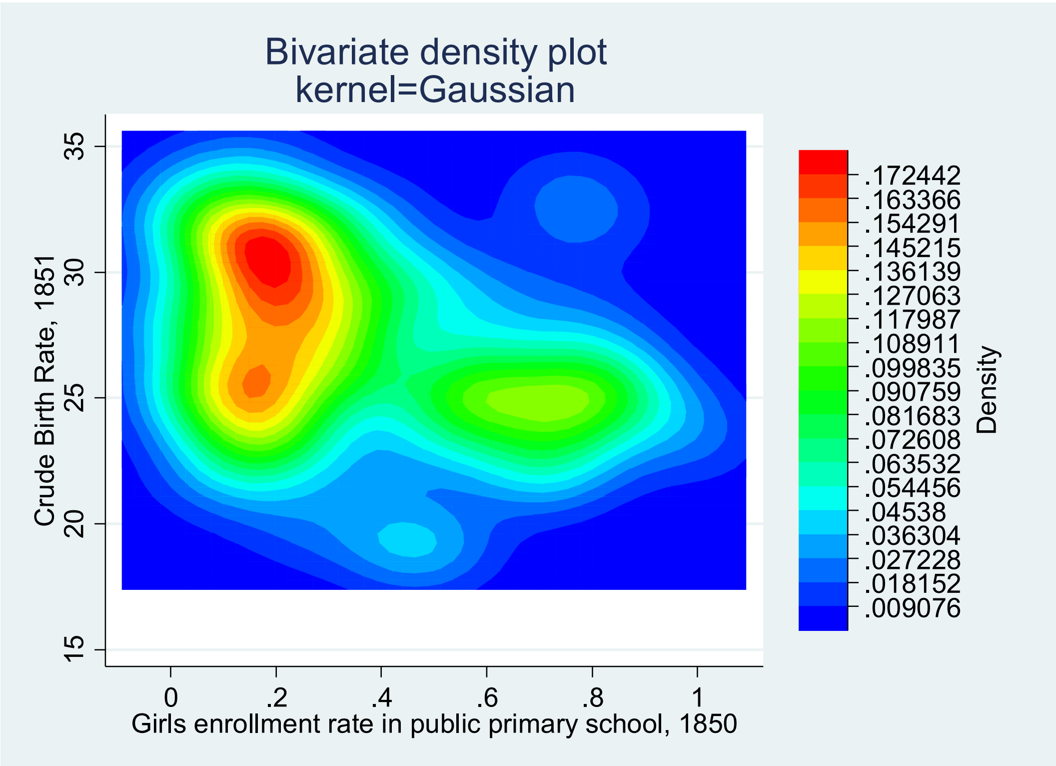


Figure 2c: Skewness Test

Figure 2c.1: Boys Enrollment

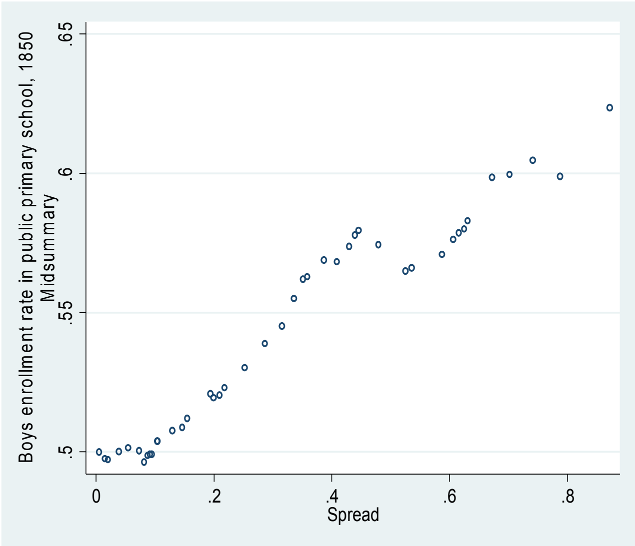


Figure 2c.2: Girls Enrollment

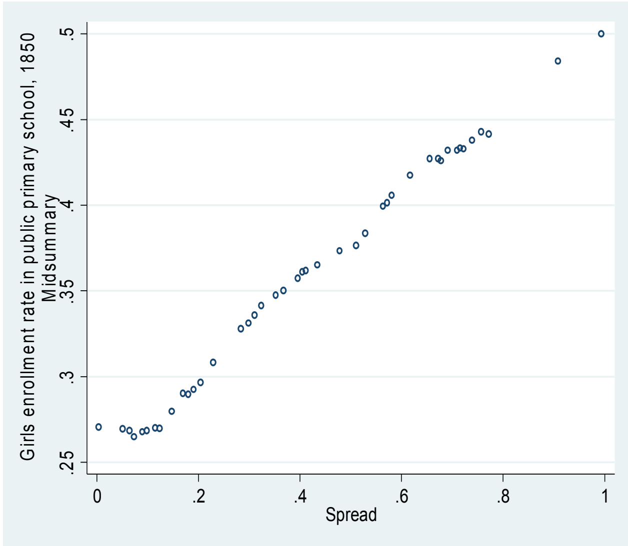
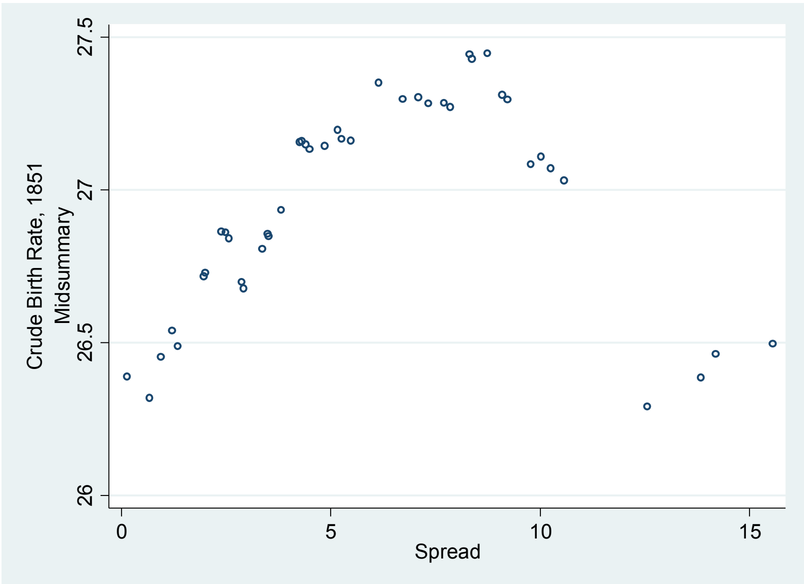


Figure 2c.3: Crude Birth Rate



4. Methodological setting

In this section we develop and present the methodological construct that would adequately account for sensitivity of the education-fertility relationship to distributional heterogeneity. Towards this end, we first describe the empirical framework and use the same to develop necessary methodological tool.

4.1 Empirical construct

Short-run

We investigate the short-run relationship between investment in human capital and fertility. Following the work done by Becker *et al.* (2010), we differentiate between the two directions of causality: from education to fertility and from fertility to education. We estimate the following empirical models separately (Wooldridge, 2002):

$$fertility_i^j = \alpha_1 + \beta_1 education_i + \boldsymbol{X}_{i1}\,\delta_1 + e_{i1} \tag{6}$$

$$education_i^k = \alpha_2 + \beta_2\, fertility_i + \boldsymbol{X}_{i2}\delta_2 + e_{i2} \tag{7}$$

where $fertility_i$ and $education_i$ refer to the crude birth rate and the enrollment rate in public primary schools for each county i. The coefficients β_1 and β_2 are our parameters of interest. $\boldsymbol{X}_1$ and $\boldsymbol{X}_2$ are the vectors of control variables.

Long-run

We use equation (8) to test the hypothesis that increasing investment in education might have played a significant role in the fertility transition:

$$\Delta fertility_{i,1881-1911} = \alpha_i + \beta\, \Delta\, education_{i,1856-70} + \boldsymbol{X}_i\ \delta + e_i \tag{8}$$

where the percentage change in the crude birth rate between 1881 and 1911 is the dependent variable and the percentage change in literacy rates between 1856 and 1870 is our variable of interest. $\boldsymbol{X}$ is the vector of control variables (see Appendix for a detailed description of the variables). The time lag of twenty five years between the dependent and the explanatory variable prevents from having a direct simultaneity between the variables.

We estimate equations (6) - (8) by using quantile regression approach. The motivations for preferring quantile method to ordinary least squares (OLS) have been presented in Section 3. Based on quantile approach (with and without instrumentation), our main incentive is to investigate: *(a)* to what extent the level of male education at time t is influenced by the level of parental fertility at time t; and *(b)* to what extent the level of girls education at time t is determined by the level of parental fertility at time t.

Indeed, investigating the relationships from a gendered perspective allows us to compare the respective effects of boys and girls education on fertility and the effect of fertility respectively on boys' education and on girls' education. We keep in mind that we suspect a bi-causal relationship between fertility and education. Unobserved characteristics affecting schooling choices are potentially correlated with unobservable factors influencing the decision to have children (and inversely). Estimating a causal relationship may consequently be biased by some potential endogeneity of each of our variables of interest. This is accounted for by employing an instrumental variable quantile regression approach. Nonetheless, our main motivation in this paper is not to measure the exact causation but to have intuitive results on the fertility-education nexus.

To control for the main determinants of fertility and education The covariates used in the regression analysis are: *(i)* proxies for the level of industrialization specified as the level of urbanization[14] and the population density; *(ii)* employment opportunities measured by the share of people making their living of agriculture and the share of people employed in manufacturing; *(iii)* the share of Protestants; and *(iv)* the life expectancy at age 0.

4.2 Estimation and identification strategy

Limitations of OLS with respect to representativeness of heterogeneity of slope estimates – especially in the presence of cross-sectional heteroscedasticity across the distribution – are well known. Moreover, as reflected in Section 3, the distributions of both education and fertility are found to possess non-unique mode necessitating the use of an alternative estimation method rather than the conventional OLS. One can, for instance employ non-parametric method and compare the distribution of the dependent variable and the regressor. However, these methods inherit the natural limitation of focusing on the *mean of the distribution* and its changes in the shape of the distribution. What is required, however, is the effect of the regressor on the entire distribution of the dependent variable. Quantile regression approach has been proved very useful in this regard (Koenker and Bassett, 1978, for instance). In quantile regression, by specifying different covariate effects at different quantile levels we allow covariates to affect not only the center of the distribution (that is mean-based OLS estimation), but also its spread and the magnitude of extreme events. Indeed, by using quantile model we allow for unobserved heterogeneity and heterogeneous covariate effects. In addition, quantile regression allows for some conditional heteroskedasticity in the model (Koenker and Portnoy, 1996), and is a method that is more robust to outliers

Recalling the quantity-quality trade-off problem in equation (6) and denoting, fertility as (F), education as (E), and other variables as (X), we can re-write the vectorial notation as follows:

$$F = \beta E + \gamma X' + \varepsilon$$

[14] The level of urbanization is defined as the share of people living in towns populated by more than 2000 inhabitants.

$$X = f(z, u) \tag{9}$$
$$\varepsilon = \mu + u$$

We assume that education (E) not only affects fertility (F) but also life expectancy, urbanization, and many other variables (denoted in our equation as X). z is a vector of instruments which drive education but are uncorrelated with u and ε. Moreover, μ are country specific factors affecting the evolution of F and E. As evident, we are interested in estimating β, the causal effect of education on fertility, at different quantiles of the conditional distribution of fertility. The following possibilities arise:

OLS based regression

In a typical least squares approach, one may focus on estimating:

$$E(F_i|E_i, X_i) = \beta E_i + \gamma X_i \tag{10}$$

In equation (10), β captures the 'average' response of fertility due to a small change in educational attainment and other variables. What is missing in this estimate is the possibility of *heterogeneous* response of fertility to changes in the explanatory variables. It is now well-known that average response of the dependent variable is less informative of the actual dynamics that occurs between the regressors and the full range of distribution of the dependent variable. Indeed, this is the case in the present context. As demonstrated before, the unconditional distribution of fertility is strongly bimodal. Thus, it seems that the analysis that focuses on the (conditional) mean of the distribution might miss important distributional effects of education and other variables on fertility. To capture this effect, quantile regression will offer a wholesome view of the effect of education on the entire distribution of fertility (or vice versa as in equation 8). Given the cross-sectional nature of our data, we adopt the following *cross-sectional quantile regression* framework.

Quantile estimation

$$Q_{F_i}(\tau|E_i, X_i) = \beta(\tau) + \gamma(\tau)X_i \tag{11}$$

The parameter $\beta(\tau)$ captures the effect of education at the τ-th quantile of the conditional distribution of fertility. This model can be estimated by solving the following minimization problem:

$$\min_{\beta,\gamma} \sum_{i=1}^{N} \rho_\tau (F_i - E_i - \gamma X_i) \tag{12}$$

where $\rho_\tau(u)$ is the standard quantile regression check function (see, e.g., Koenker and Bassett, 1978; Koenker, 2005). The partial effects for education on fertilty can be obtained by $\frac{\partial Q_t(F_i|E_i)}{\partial E_i}$.

Identification strategy – *Endogeneity issue*

Two types of endogeneity problems can plague regressions of education on fertility. One type is the simultaneity bias introduced by the reverse causality of education and fertility (eq. 8). A second type of endogeneity problem arises from omitted variable bias. While including policy variables helps reduce the problem of the endogeneity of education, it is still quite plausible that a third variable jointly causes both fertility and education – perhaps religious, cultural or geographic factors. In order to mitigate the problems of endogeneity, we innovate upon the previous literature by employing an instrumental variables approach in our cross-sectional quantile regression (see for instance, Chernozhukov and Hansen (2005) and Harding and Lamarche (2009) for detailed estimation procedures). The question may arise on the choice of instruments. Because we have two different channels (fertility to education and the reverse) for quantifying quantity-quality trade-off, several possible instruments can be considered. In case of fertility-education channel (equation 6), there are a number of possibilities for instrumenting education. For instance, one can use enrollment in 1851, distance to Mainz, share of male (female) spouse signing the contract 1816-20, landownership inequality in 1835, agricultural inequality, public primary schools for 100 boys and girls. Murphy (2015), interestingly noted that 'no valid instruments were available' for France to deal with the problem of potential endogeneity of education. However, the mentioned potential instruments in our paper (as will be explained in the following section), work well as alternative measures for instruments of education in France.

Similarly, when we consider the reverse channel, i.e., education-fertility relationship, the possible instruments for fertility are crude birth rate of the previous generation (in 1821), adult sex ratio 15-45 , share of dependent children in 1851, children and non-married sex ratio in 1821, 1831, and 1836. As we know, all instruments may not identify the dependent variable and may suffer from weak-identification problem. Moreover, many of them may not be strictly exogenous. The possibility of weak correlation of the instruments with other regressors in the two different channels we are interested in estimating can make estimated coefficients unreliable. Therefore, we have performed a Principal Component Analysis of the instruments as well as have performed overidentification test for the purpose. Accordingly, we have chosen the adult sex ratio and the share of dependent children as instruments for fertility, whereas the distance to Mainz and the share of male (female) spouse signing their marriage contract in 1816-20 have been chosen as instruments for education.

5. Results

5.1 Short-run Effects: From Education to Fertility

Two types of results are presented, viz., quantile regression estimates without accounting for endogeneity bias, and quantile regression estimates accounting for possible endogeneity. Estimations have been performed for both men and women at 10th, 25th, 50th, 75th, and 90th quantiles. To minimize space, we have reported in all Tables lower quantile ($\tau = 25^{th}$), median quantile ($\tau = 50^{th}$ – generally regarded as an approximate to OLS estimates), and an upper quantile ($\tau = 75^{th}$).

We begin with the case where the dependent variable is fertility (crude birth rate). In all tables, the results are presented in three columns (quantile estimation for each case). Beginning with the restrictive model where only fertility and education variables are considered (model 1), we continue to add more explanatory variables with education: the role of agriculture, industry, urbanization, and population density (model 2), the role of share of Protestants (model 3), and the potential role of life expectancy at birth (model 4).

OLS estimates

Overall, looking at all columns, across quantiles, and for both men and women, we find evidence of a quality-quantity trade-off in the short-run, although the magnitudes are observed to vary across the distribution of the dependent variable in question. The 50th quantile – which approximates OLS estimates – shows that the coefficient for education is significant at the 0.1% and negative for both genders. As per the estimates of median quantile, we observe in Table 2 that in more densely populated environments, fertility rates are significantly lower (at 0.1%), whereas in more urbanized counties, fertility rates are higher (at 5%). In line with the latter result, counties with a larger share of male employed in manufacturing exhibit significantly higher fertility rates (at 5%). This result may be due to a positive income effect. The male wages are likely to be higher in counties where the industry is more developed what is expected to increase the demand for children. Contrary to what has been found by Becker *et al.* (2010) for Prussia, fertility is significantly higher (at 1%) in counties where the share of Protestants is larger (see Table 2 and Table 3). Life expectancy at age 0, however, is negatively associated with fertility. The life expectancy at age 0 is expected to capture the variations in infant mortality. According to the adaptation hypothesis, the decline in infant mortality might have induced individuals to act such as maintaining a sustainable number of offspring by reducing their fertility. Whatever the specification of equation (6), the coefficient of education remains strongly significant and negative for both boys and girls. These results seem to confirm the existence of a negative effect of child quantity on the child quality.

Are the results found at median quantile (50th quantile) significantly different than at low (25th) and high (75th) quantiles? Do we observe a consistency in the estimated coefficients? The direction and magnitude of effects can be gauged by examining the sensitivity of results at various quantiles of the dependent variable. For the restricted model (column 1 to 3), as well as for broader models (models (2) to (4) – column 4 through column 12), the effect of education has been found to be both negative and significant at 1% level (see Table 2). In comparison to the median quantile, both lower and upper quantile estimates of the effect of education on fertility have been found to be small and negative with magnitude of effects at higher quantile observed to be smaller than the one obtained at lower quantile (column 1-column 3). Similar patterns are observed in Table 3 (for women). A monotonic decline in the magnitude of coefficients (although negative) is noted in model (4) (columns 10 to 12) for both Tables 2 and 3 where the most general model is estimated. The heterogeneity in the estimated coefficient of education on fertility (as observed in Tables 2 and 3), clearly demonstrates that OLS based estimates may under-represent the significant variability in the estimates, that is, the response of negative effect of education on fertility being smallest at higher quantile and largest at smaller quantile (column 10 and 12 respectively, in the most general model). Moreover, the R^2 value is found to be greatest for the most general model (with a value of 0.402 at 50th quantile) in comparison to 0.123 (for the restricted model, column 1). Of course, within quantile heterogeneity in R^2 is also observed, implying that the same explanatory variable can have variable predictive power for counties at smaller quantile of fertility distribution than at median and higher quantiles.

IV estimates

While quantile estimates in Tables 2 and 3 are reflective of the general trend in the empirical literature in quantity-quality trade-off, these may not be taken seriously if there is a possibility of endogeneity bias in the relationship between fertility and education, and vice versa. In the preceding section, we have provided the mechanism and logic of the use of instrumental variable while performing quantile regressions. Table 4 and 5 report the IV estimates of equation (6) where the dependent variable is the crude birth rate. Clearly, as distinct from Tables 2 and 3, we find that, for each model specification and quantile, the estimated coefficients of education on fertility are consistently smaller at higher than at lower quantile.

In Tables 4 and 5, interesting insights emerge on the variable effect of education on fertility when education is being instrumented by distance to Mainz. First, we observe that the effect of urbanization on fertility rates has moved from being negative but insignificant at lower quantile (column 4) to becoming positive and significant at higher quantile (for male). In comparison to the estimates at median quantile – where it was observed that at more densely populated environments fertility rates are significantly lower, whereas in more urbanized counties fertility rates are higher – in IV regression, the results seem consistent at 25th quantile. The trend seems to get reversed and in some cases the effects disappear at higher quantile, depicting once again the necessity of using full distributional assumption than undertaking inference at only ‘mean’ based estimates.

Table 2: Quantile regression results - education to fertility: Men

	Crude Birth Rate											
Dependent Variable	(1)			(2)			(3)			(4)		
	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$
Boys enrollment	-1.998***	-10.005***	-7.774**	-1.941***	-10.436***	-9.801***	-2.153***	-11.330***	-10.961***	-1.125*	-6.708***	-7.880***
	(.613)	(2.455)	(2.496)	(0.649)	(2.651)	(2.582)	(.649)	(2.579)	(2.573)	(0.684)	(2.521)	(1.975)
Male in agriculture				2.108**	5.053	-0.338	1.741*	3.503	-2.349	1.302	1.660	-3.517
				(1.043)	(5.471)	(4.337)	(1.061)	(5.508)	(4.202)	(0.846)	(4.198)	(3.817)
Male in industry				2.583**	12.040**	2.014	2.578**	12.018***	1.987	1.056	5.162	-2.588
				(1.027)	(4.781)	(4.951)	(0.997)	(4.462)	(5.117)	(1.153)	(4.080)	(6.365)
Urbanization				20.561***	83.342**	130.658**	13.754**	54.622	93.411**	10.476*	39.340	82.977**
				(7.353)	(37.846)	(41.879)	(6.988)	(37.590)	(42.463)	(5.890)	(34.226)	(40.870)
Population density				-0.412**	-1.686**	-3.192***	-0.265*	-1.066	-2.388**	-0.248**	-0.992	-2.340**
				(0.159)	(0.834)	(0.927)	(0.148)	(0.820)	(0.936)	(0.126)	(0.772)	(0.918)
Share Protestants							0.043**	0.184**	0.239***	0.024	0.093	0.176**
							(0.016)	(0.086)	(0.070)	(0.021)	(0.087)	(0.070)
Life expectancy										-0.144**	-0.699***	-0.489***
										(0.028)	(0.101)	(0.110)
Constant	26.123***	31.832***	35.002***	24.211***	26.941***	35.674***	24.548***	28.363***	37.517***	30.031***	54.859***	56.023***
	(.313)	(1.480)	(1.664)	(1.005)	(5.145)	(4.609)	(1.020)	(5.112)	(4.462)	(1.238)	(5.653)	(6.579)
N	86	86	86	86	86	86	86	86	86	85	85	85
R^2	0.101	0.123	0.090	0.167	0.180	0.244	0.191	0.201	0.291	0.362	0.402	0.423
F	10.62***	16.6***	9.70***	7.57***	19.61***	7.12***	7.18***	17.79***	11.08***	9.82***	37.78***	11.05***

Quantile regressions. Dependent variable: crude birth rate. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Crude birth rate is defined as the number of birth (in 1000 s) over the total population. Boys enrollment rate is the share of boys aged 6-14 enrolled in public primary schools.
Source: County-level data from the *Statistique Générale de la France*.

Table 3: Quantile regression results - education to fertility: Women

	Crude Birth Rate											
Dependent Variable	(1)			(2)			(3)			(4)		
	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$
Girls enrollment	-1.594**	-7.603***	-5.105***	-1.714**	-8.895***	-7.371***	-1.778***	-9.136***	-7.700***	-0.642	-3.926*	-4.142**
	(0.542)	(2.252)	(2.044)	(0.549)	(2.228)	(1.911)	(0.540)	(2.213)	(1.866)	(0.599)	(2.264)	(1.453)
Female in agriculture				1.467*	1.928	-4.183	1.311	1.356	-4.963	1.005	0.205	-5.737
				(0.848)	(4.258)	(3.922)	(0.847)	(4.269)	(3.379)	(0.665)	(3.368)	(3.557)
Female in industry				3.448**	13.814***	0.245*	3.459**	13.857***	0.303	1.601	5.583	-5.335
				(1.093)	(5.486)	(4.035)	(1.081)	(5.247)	(3.872)	(1.103)	(4.226)	(4.298)
Urbanization				18.229***	75.696**	119.843**	12.925**	55.631	92.474**	4.985	18.543	67.118
				(6.428)	(36.11)	(41.88)	(5.902)	(35.123)	(42.018)	(5.652)	(36.588)	(43.667)
Population density				-0.368***	-1.528*	-2.958**	-0.248*	-1.074	-2.339***	-0.130	-0.521	-1.961**
				(0.142)	(0.809)	(0.934)	(0.130)	(0.787)	(0.939)	(0.125)	(0.825)	(0.981)
Share Protestants							0.037***	0.142*	0.194***	0.016	0.040	0.124
							(0.013)	(0.085)	(0.078)	(0.016)	(0.091)	(0.089)
Life expectancy										-0.141***	-0.677***	-0.463***
										(0.024)	(0.087)	(0.138)
Constant	25.609***	29.112***	32.609***	24.474***	27.256***	35.497***	24.537***	27.494***	35.822***	30.300***	54.880***	54.568***
	(0.210)	(1.066)	(2.044)	(0.645)	(3.223)	(3.267)	(0.641)	(3.205)	(3.171)	(1.032)	(4.770)	(7.303)
N	86	86	86	86	86	86	86	86	86	85	85	85
R^2	0.101	0.123	0.090	0.167	0.180	0.244	0.191	0.201	0.291	0.362	0.402	0.423
F	10.62***	16.6***	9.70***	7.57***	19.61***	7.12***	7.18***	17.79***	11.08***	9.82***	37.78***	11.05***

Quantile regressions. Dependent variable: crude birth rate. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Crude birth rate is defined as the number of birth (in 1000 s) over the total population. Girls enrollment rate is the share of girls aged 6-14 enrolled in public primary schools.
Source: County-level data from the *Statistique Générale de la France*.

Table 4: IV Quantile regression results - education to fertility: Men

	Crude Birth Rate											
Dependent Variable	(1)			(2)			(3)			(4)		
	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$
Boys enrollment	-4.533**	-4.463***	-10.041***	-3.250**	-4.137***	-9.762***	-3.280*	-4.167***	-9.529***	-6.677***	-6.743***	-7.859***
	(2.307)	(1.066)	(1.161)	(1.782)	(0.020)	(2.288)	(1.698)	(0.020)	(2.482)	(1.941)	(1.776)	(2.648)
Male in agriculture				7.777*	4.827	2.979	11.740***	5.756*	0.596	9.776***	17.430***	2.109
				(4.413)	(3.667)	(3.188)	(4.702)	(3.066)	(4.261)	(3.859)	(7.264)	(3.676)
Male in industry				14.469*	6.121	4.949	14.269*	7.112	2.098	-1.853	-8.964	12.528***
				(7.970)	(6.117)	(7.020)	(8.496)	(6.003)	(7.601)	(5.950)	(6.281)	(5.017)
Urbanization				103.513**	63.360**	83.544**	121.726***	70.332**	42.225*	-3.083	39.537*	35.038*
				(44.141)	(32.513)	(30.343)	(48.729)	(34.722)	(24.672)	(32.926)	(21.443)	(21.757)
Population density				-5.004***	-1.283*	-1.939**	-3.367	-1.409*	-1.887	-1.385	-0.206	-1.812
				(2.788)	(0.735)	(0.680)	(3.027)	(0.782)	(2.671)	(2.049)	(1.875)	(2.026)
Share Protestants							0.098	0.161*	0.169*	0.083	0.003	0.086*
							(0.132)	(0.088)	(0.095)	(0.089)	(0.082)	(0.052)
Life expectancy										-0.532***	-0.649***	-0.508***
										(0.095)	(0.101)	(0.093)
Constant	26.906***	29.172***	34.587***	21.149***	24.801***	31.018***	13.850***	23.426***	33.955***	48.184***	47.726***	49.964***
	(1.273)	(0.541)	(0.590)	(4.636)	(3.113)	(4.083)	(4.450)	(3.067)	(3.328)	(5.038)	(4.610)	(5.170)
N	86	86	86	86	86	86	86	86	86	85	85	85
R^2	0.112	0.129	0.107	0.174	0.184	0.231	0.202	0.240	0.301	0.379	0.425	0.410
F	12.35***	16.87***	10.66***	9.36***	19.55***	8.19***	7.68***	17.98***	12.01***	9.83***	38.98***	11.56***

Instrumental variable quantile regressions. Dependent variable: crude birth rate. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Crude birth rate is defined as the number of birth (in 1000 s) over the total population. Boys enrollment rate is the share of boys aged 6-14 enrolled in public primary schools. Instrument for enrollment rate is Distance to Mainz. The instrument has been chosen from a set of comparative indicators based on overidentification test.
Source: County-level data from the *Statistique Générale de la France*.

Table 5: IV Quantile regression results - education to fertility: Women

	Crude Birth Rate											
Dependent Variable	(1)			(2)			(3)			(4)		
	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$
Girls enrollment	-3.233**	-5.552***	-9.692***	-6.707**	-7.952***	-10.062***	-5.223**	-7.466***	-9.160***	-5.736	-8.859**	-9.572*
	(1.91)	(2.479)	(2.816)	(2.949)	(2.503)	(3.022)	(2.653)	(2.763)	(2.986)	(2.352)	(2.350)	(2.512)
Female in agriculture				0.186	2.357	-1.233	0.034	3.104	-0.934	2.162	-2.370	-0.437
				(3.725)	(3.431)	(3.816)	(3.353)	(3.811)	(3.738)	(3.209)	(2.636)	(2.819)
Female in industry				14.355**	11.446***	5.838	12.400**	10.718**	3.806	14.018**	1.159	-0.153
				(6.928)	(4.862)	(9.203)	(5.356)	(5.590)	(9.053)	(7.140)	(6.607)	(7.065)
Urbanization				72.608*	58.786*	30.082	59.245*	57.088*	21.346	-42.442**	-4.534	26.184
				(42.55)	(32.049)	(43.595)	(34.745)	(35.350)	(43.138)	(20.843)	(31.173)	(33.333)
Population density				-1.549	-1.587	-1.881	-0.554	-1.107	0.072	3.693**	-0.076	4.876
				(2.796)	(2.240)	(2.865)	(2.325)	(2.546)	(2.844)	(1.764)	(2.031)	(1.979)
Share Protestants							0.100	0.145*	0.061	0.131**	0.039	-0.077
							(0.100)	(0.090)	(0.120)	(0.092)	(0.085)	(0.104)
Life expectancy										-0.428***	-0.628***	-0.429***
										(0.107)	(0.089)	(0.099)
Constant	25.542***	28.812	32.958***	26.109***	27.367***	34.378***	24.985***	26.184***	32.372***	42.196***	52.850***	47.471***
	(0.948)	(0.858)	(0.975)	(3.445)	(3.258)	(3.530)	(3.009)	(3.701)	(3.504)	(4.508)	(4.281)	(4.577)
N	86	86	86	86	86	86	86	86	86	85	85	85
R^2	0.100	0.125	0.102	0.184	0.210	0.201	0.187	0.201	0.307	0.354	0.442	0.406
F	11.34***	16.9***	9.88***	8.74***	16.32***	8.90***	7.68***	16.22***	12.21***	10.02***	31.61***	11.80***

Instrumental variable quantile regressions. Dependent variable: crude birth rate. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Crude birth rate is defined as the number of birth (in 1000 s) over the total population. Girls enrollment rate is the share of girls aged 6-14 enrolled in public primary schools. Instrument for enrollment rate is Distance to Mainz. The instrument has been chosen from a set of comparative indicators based on overidentification test.
Source: County-level data from the *Statistique Générale de la France*.

5.2 Short-run Effects: From Fertility to Education

The discussion of results in the preceding section focused on education-fertility channel with the relationship running from education to fertility. To further qualify evidence on quality-quantity hypothesis, we present, in this section, results by considering reverse causality, i.e., from fertility to education. Tables 6 and 7 report Instrumental variable quantile regression estimates of the education equation (7), where boys and girls enrollment rates are each in turn function of the crude birth rate. Unlike the education-fertility channel, we do not present here the Quantile regression results without treatment of endogeneity bias, as we have argued before that possible endogeneity can plague OLS or quantile estimates. Hence, we are inclined to present only IV quantile estimates. The reason for undertaking reverse causality has been stated earlier; however, at this point we should note that we are not interested in testing causality of quantity-quality trade-off hypothesis. This can be an interesting exercise which we reserve for future research. In what we present in terms of estimation strategy of the trade-off is the observed empirical approaches undertaken in the extant literature (e.g. Becker *et al.*, 2010).

Accordingly, following the reverse form of causality[15], the school enrollment rate is the dependent variable and the crude birth rate is our variable of interest. To treat possibility of endogeneity of fertility with other regressors, we have instrumented crude birth rate with adult sex ratio. Tables 6 and 7 report the estimates where boys and girls enrollment rates are each in turn function of the crude birth rate. Column 1 displays the estimation results without any control variables. Models 2 to 4 report estimation results adding different set of control variables. As before, we present estimates for three quantiles (25th, 50th, and 75th). Regardless the specification and distribution of heterogeneity, the coefficient of fertility is significant and negative at least at the 1% level which confirms the significant and robust association from fertility to education.

Tables 6 and 7 present interesting findings with respect to Instrumental variable quantile regressions. Overall results indicate stronger effects of fertility decline on the likelihood of female empowerment with respect to education. Both at 50th and 25th quantile, Tables 6 and 7 (without introduction of controls, i.e., the restricted model) clearly show that fertility decline exerted greater effects on girls' enrollment rate that on boys' enrollment rate. Of course, when controlling for the role of men and women in agriculture and industry, as well as the effect of urbanization and population density (model 2 in Table 6 and 7), the results yet point at the larger role of women, than men. Our interquartile difference test for men-women differences in results in each quantile also rejects the null hypothesis of no significant effect in favor of greater effects of women (at 5% levels: results not reported here).

[15] Test of causality in cross-sectional regression of the type we have presented in this paper can be performed either by matching or by spatial causality test. We reserved this for future research.

Moreover, a striking result merits attention: while urbanization seems to have exerted significant effect on boys' enrollment, while controlling for fertility, the same variable does not appear to affect girls' enrollment at all.[16] Contrastingly, those women who might have already been residing in urban environment are found to experience a boost toward enrollment in public primary schools by participating in industry work. In addition, higher life-expectancy for women had larger positive and significant effects on the enrollment rates than the life expectancy of men for all quantiles. Conversely, higher share of Protestants had positive and significant effects on the propensity to invest in boys' enrollment rates (at 25th and 75th quantiles in Table 6); but not to invest in girls' education.

The estimates of equation (6) and equation (7) confirm the existence of a mutual negative and significant relationship between fertility and education, supporting the existence of a child quantity-quality trade-off in 1851 France. Hence, counties in which the increase in education has been more important account for larger changes in fertility, and conversely. These results are coherent with the interpretation of the unified growth theory (Galor and Moav, 2002; Galor, 2005; Diebolt and Perrin, 2013). Yet, the decisions about quality and quantity of children being taken simultaneously, the analysis does not allow us to conclude about the causality between education and fertility.

[16] This result might be due to the fact that urbanization often motivates the migration of men workers more than the migration of women, rightly so in the historical episodes this study is based on.

Table 6: IV Quantile regression results - fertility to education: Men

	Boys enrollment rate											
Dependent Variable	(1)			(2)			(3)			(4)		
	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$
Crude Birth Rate	-0.017***	-0.015**	-0.039**	-0.017***	-0.019**	-0.038**	-0.017***	-0.023***	-0.043***	-0.015**	-0.021**	-0.058**
	(0.004)	(0.007)	(0.014)	(0.004)	(0.008)	(0.012)	(0.003)	(0.008)	(0.010)	(0.005)	(0.009)	(0.018)
Male in agriculture				-0.006	-0.101	-0.222	-0.040	-0.134	-0.312	-0.069	-0.133	-0.584
				(0.187)	(0.190)	(0.322)	(0.161)	(0.222)	(0.336)	(0.159)	(0.201)	(0.360)
Male in industry				0.315	0.331	0.095	0.379	0.332	0.041	0.398	0.319	-0.468
				(0.388)	(0.578)	(0.669)	(0.388)	(0.601)	(0.596)	(0.403)	(0.602)	(0.760)
Urbanization				3.015	5.576**	6.425**	1.222	4.569**	0.443	0.975	3.096	2.718
				(2.552)	(2.841)	(3.229)	(2.344)	(2.369)	(2.369)	(2.059)	(2.553)	(3.150)
Population density				-0.075	-0.136	-0.163	-0.031	-0.113	-0.026	-0.025	-0.078	-0.096
				(0.087)	(0.122)	(0.157)	(0.085)	(0.123)	(0.173)	(0.087)	(0.131)	(0.156)
Share Protestants							0.009*	0.007	0.018***	0.010**	0.007	0.015**
							(0.005)	(0.006)	(0.007)	(0.004)	(0.005)	(0.006)
Life expectancy										0.002	0.0009	-0.021
										(0.005)	(0.008)	(0.016)
Constant	0.850***	0.923***	1.733***	0.854***	1.053***	1.864***	0.873***	1.163***	2.060***	0.739**	1.079**	3.623***
	(0.115)	(0.232)	(0.395)	(0.228)	(0.282)	(0.338)	(0.229)	(0.330)	(0.378)	(0.343)	(0.542)	(0.988)
N	86	86	86	86	86	86	86	86	86	85	85	85
R^2	0.100	0.125	0.102	0.173	0.147	0.195	0.217	0.174	0.238	0.221	0.176	0.232
F	11.34***	16.9***	9.88***	9.39***	74.20***	28.73***	3.60**	16.22***	12.21***	10.59***	38.22***	12.56***

Instrumental variable quantile regressions. Dependent variable: crude birth rate. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Crude birth rate is defined as the number of birth (in 1000 s) over the total population. Boys enrollment rate is the share of boys aged 6-14 enrolled in public primary schools. Instrument for CBR is Adult sex ratio. The instrument has been chosen from a set of comparative indicators based on overidentification test.
Source: County-level data from the *Statistique Générale de la France*.

Table 7: IV Quantile regression results - fertility to education: Women

	Girls enrollment rate											
Dependent Variable	(1)			(2)			(3)			(4)		
	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$
Crude Birth Rate	-0.020**	-0.018**	-0.022*	-0.02**	-0.020***	-0.024**	-0.021***	-0.021***	-0.026***	-0.019**	-0.025**	-0.051**
	(0.006)	(0.011)	(0.005)	(0.005)	(0.010)	(0.005)	(0.005)	(0.010)	(0.004)	(0.009)	(0.017)	(0.006)
Female in agriculture				-0.277*	-0.300**	-0.501**	-0.282*	-0.307**	-0.528**	-0.230**	-0.253**	-0.412*
				(0.126)	(0.255)	(0.162)	(0.128)	(0.259)	(0.101)	(0.124)	(0.246)	(0.126)
Female in industry				0.584**	0.569**	0.114	0.583**	0.568**	0.110	0.682**	0.668**	0.306*
				(0.276)	(0.430)	(0.248)	(0.274)	(0.429)	(0.234)	(0.263)	(0.169)	(0.276)
Urbanization				1.532	2.279	3.670	1.268	1.963	2.390	1.327	2.024	2.520
				(2.152)	(3.712)	(2.025)	(2.152)	(3.128)	(2.156)	(2.307)	(3.259)	(2.152)
Population density				-0.044	-0.061	-0.099	-0.038	-0.054	-0.069	-0.034	-0.050	-0.063
				(0.048)	(0.084)	(0.045)	(0.048)	(0.070)	(0.048)	(0.051)	(0.073)	(0.048)
Share Protestants							0.002	0.002	0.009	0.002	0.002	0.010
							(0.005)	(0.101)	(0.004)	(0.004)	(0.008)	(0.005)
Life expectancy										0.012**	0.012**	0.020**
										(0.005)	(0.009)	(0.005)
Constant	0.792***	0.902***	1.139***	0.961***	1.101***	1.493***	0.972***	1.116***	1.554***	0.878**	0.272**	0.987**
	(0.181)	(0.186)	(0.333)	(0.193)	(0.369)	(0.338)	(0.193)	(0.195)	(0.365)	(0.349)	(0.110)	(0.419)
N	86	86	86	86	86	86	86	86	86	85	85	85
R^2	0.100	0.114	0.09	0.213	0.240	0.125	0.219	0.243	0.140	0.247	0.268	0.109
F	9.84**	7.94**	3.63*	12.11***	4.12**	3.60**	10.00**	7.87***	3.40**	8.25***	6.60***	4.99***

Instrumental variable quantile regressions. Dependent variable: crude birth rate. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Crude birth rate is defined as the number of birth (in 1000 s) over the total population. Girls enrollment rate is the share of girls aged 6-14 enrolled in public primary schools. Instrument for CBR is Adult sex ratio. The instrument has been chosen from a set of comparative indicators based on overidentification test.
Source: County-level data from the *Statistique Générale de la France*.

5.3 Long-run Effect of Human Capital on Fertility Transition

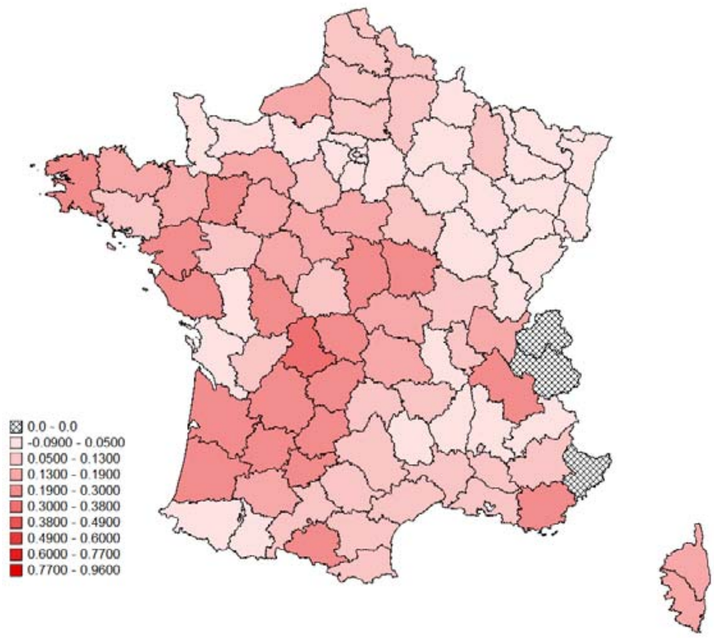
From the study of the short-run relationship between education and fertility, our results show that the correlation goes in both directions of causation. This suggests the existence of a child quantity-quality trade-off in France during the French demographic transition. However, these results may hide a more complex underlying relationship, as advanced by Diebolt and Perrin (2013b). Henceforth, we test in this section the hypothesis that women endowments in human capital affect their own choices of fertility, and subsequently that of future generations. The objective of this study is then to determine whether the endowments in human capital in time t affect the level of fertility in period $t + 1$.

This motivates us to model the long-run effect of investment in human capital on fertility. We empirically test the effect of the percentage change in human capital investments between 1856 and 1870 on the variations in fertility between 1881 and 1911 across French counties. The motivation of such choice of data is to account for the effect of education on several generations of individuals (parents and grand-parents).

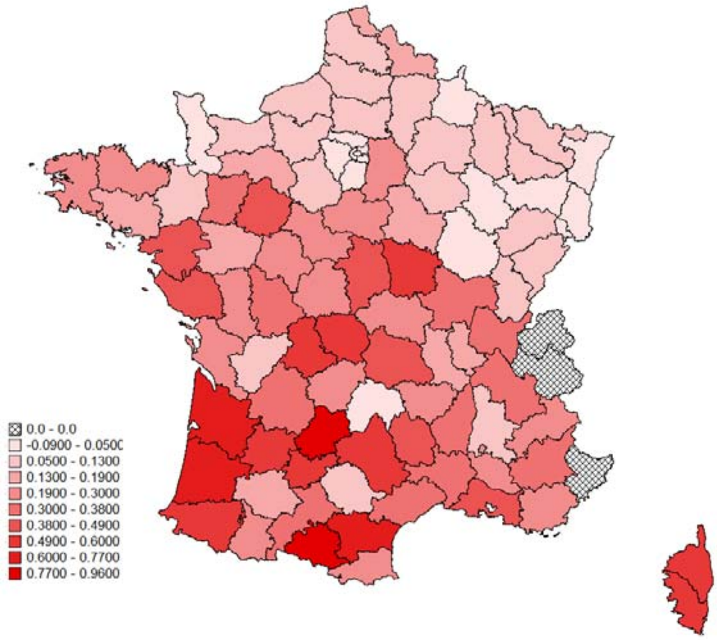
Figures 3a and 3b give us an insight on the geographical distribution of changes in male and female literacy rates between 1856 and 1870, while Figure 3c provides an insight of the subsequent changes in crude birth rates, in particular between 1881 and 1911. Contrary to the agricultural and rural areas, the most industrialized area of France (Northeast) display lower variations in female literacy rates over the period studied. Comparatively, we see that counties experiencing stronger improvement in female literacy rates over the period 1856-1870 tend also to experience a steeper fertility decline (measured by the percentage change in crude birth rate over the period 1881-1911).

Figure 3: Geographical Distribution of the Percentage Change in Education and Fertility

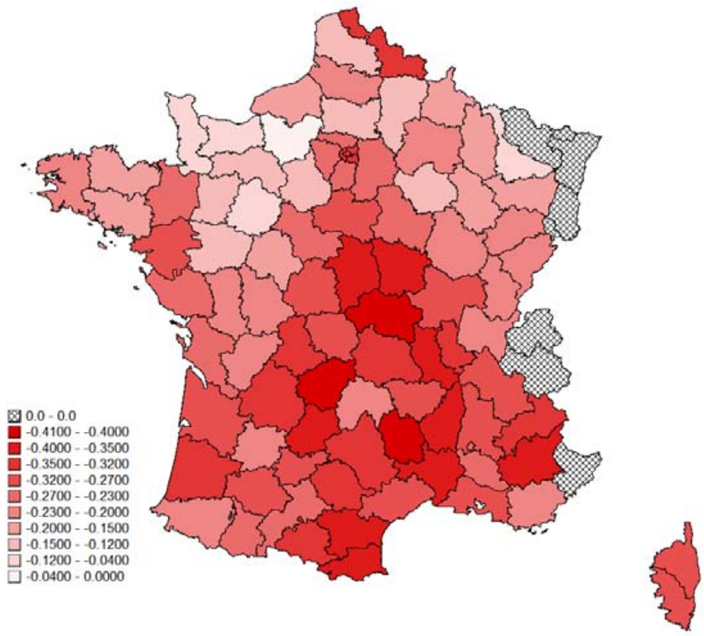
(3a) Male Human Capital, 1856-70



(3b) Female Human Capital, 1856-70



(3c) Crude Birth Rate, 1881-1911



Sources: Using data from Statistique Générale de la France – Enseignement Primaire; Census

We estimate equation (8) using quantile regressions. We use various specifications to study how male and female endowments in human capital affect their future fertility, introducing successively the following covariates: *(i)* the crude birth rate in 1851; *(ii)* proxies for the level of industrialization specified as the level of urbanization and the population density; *(iii)* employment opportunities measured by the share of people making their living of agriculture and the share of people employed in manufacturing; *(iv)* the share of Protestants; *(v)* the life expectancy at age 0; and *(vi)* the crude birth rate in 1881.

Long-run estimates

Tables 8 and 9 report the estimation results on the hypothesis that increasing educational investments have played a significant role in the fertility transition. Models 1 to 4 present various specifications of equation (8) for boys (Table 8) and girls (Table 9). Hence, we control for socio-economic factors adding successively control variables for employment opportunities and urbanization (model 1), religion (model 2), life expectancy (model 3) and crude birth rate in 1881 (model 4).[17]

We find very interesting results from a gendered perspective. The Quantile estimates show that the percentage change in literacy rates is negatively associated with the fertility transition. This result is strongly significant for women only. This result is in line with Diebolt and Perrin (2013) and supports the hypothesis that women behavior is at the chore of the demographic transition. It suggests that the more women are educated today, the fewer children they have tomorrow. Table 9 shows particularly strong results for all specifications (at 0.1%).

Contrary to what found by Galloway *et al.* (1998) and Becker *et al.* (2010), our coefficients do not indicate that the fertility transition is stronger in urbanized area. Contrary also to the results found on the short-run, the coefficients indicate that the fertility transition is stronger in areas where individuals are more oriented toward agriculture.[18] Similarly, the transition is also stronger in areas with a higher share of Protestants. In the complete specification reported in model 4 (Table 9), we observe that an increase in the variation of the female literacy rate by 10% is likely to decrease the variation of the birth rate by 2.3 percentage point. In terms of explanatory power, the richest model (column 10 to 12 – Table 9) accounts for more than 50% of the variation across counties of the variations in the crude birth rate.

[17] In order to test the robustness of our results, we add the initial level of birth rate in 1881.

[18] Note that agricultural areas are also those where education levels were historically the lowest and where fertility was the most important (in comparison with industrialized areas).

Table 8: Long-run results for education and fertility: Men

Dependent Variable	Crude Birth Rate (% change 1881-1911)											
	(1)			(2)			(3)			(4)		
	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$
Male literacy	-0.028	-0.274*	-0.252*	-0.061	-0.301*	-0.271*	-0.063	-0.305*	-0.087	-0.075	-0.204	-0.002
(% change 1856-70)	(0.149)	(0.157)	(0.152)	(0.150)	(0.159)	(0.156)	(0.151)	(0.160)	(0.160)	(0.167)	(0.167)	(0.162)
Crude birth rate 1851	-0.019***	-0.017***	-0.014***	-0.018***	-0.016***	-0.013***	-0.017**	-0.013***	-0.103**	-0.016***	-0.024***	-0.020***
	(0.004)	(0.004)	(0.003)	(0.004)	(0.004)	(0.003)	(0.005)	(0.004)	(0.004)	(0.008)	(0.006)	(0.005)
Male in agriculture	-0.231*	-0.210**	-0.194**	-0.220*	-0.201*	-0.188*	-0.221*	-0.203*	-0.185*	-0.213*	-0.266**	-0.238**
	(0.124)	(0.107)	(0.098)	(0.126)	(0.108)	(0.098)	(0.128)	(0.107)	(0.098)	(0.131)	(0.114)	(0.102)
Male in industry	-0.088	0.148	0.297*	-0.091	0.145	0.296*	-0.080	0.174	0.702***	-0.071	0.101	0.639***
	(0.276)	(0.185)	(0.161)	(0.283)	(0.187)	(0.162)	(0.289)	(0.210)	(0.142)	(0.294)	(0.193)	(0.128)
Urbanization	-0.620	-1.880	-2.487*	-0.505	-1.784	-2.422*	-0.512	-1.803	-1.032	-0.538	-1.585	-0.844
	(1.464)	(1.387)	(1.311)	(1.491)	(1.388)	(1.312)	(1.517)	(1.141)	(0.878)	(1.540)	(1.235)	(0.893)
Population density	-0.004	0.045	0.058	-0.009	0.041	0.056	-0.011	0.036	-0.036	-0.006	0.001	-0.066
	(0.114)	(0.113)	(0.100)	(0.114)	(0.113)	(0.100)	(0.114)	(0.114)	(0.075)	(0.122)	(0.092)	(0.057)
Share Protestants				-0.002	-0.002	-0.001	-0.002	-0.002	-0.002	-0.002	-0.003	-0.003
				(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)
Life expectancy							0.001	0.004	0.008*	0.001	0.006	0.010**
							(0.005)	(0.005)	(0.004)	(0.005)	(0.004)	(0.004)
Crude birth rate 1881										-0.001	0.015**	0.013**
										(0.005)	(0.007)	(0.006)
Constant	0.419***	0.411***	0.338**	0.404**	0.398***	0.330**	0.317**	0.157	0.537	0.329**	0.574***	0.139**
	(0.122)	(0.113)	(0.110)	(0.126)	(0.115)	(0.110)	(0.156)	(0.306)	(0.277)	(0.139)	(0.119)	(0.062)
N	82	82	82	82	82	82	82	82	82	82	82	82
R^2	0.341	0.391	0.369	0.347	0.396	0.372	0.348	0.400	0.420	0.349	0.462	0.456
F	7.61***	15.27***	14.64***	7.65***	14.81***	12.45***	6.42***	12.56***	11.04***	5.83***	14.09***	11.43***

Quantile regressions. Dependent variable: Percentage change in crude birth rate 1881-1911. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Crude birth rate is defined as the number of birth (in 1000 s) over the total population. Male literacy rate is the percentage change in the share of who signed their wedding contract between 1856 and 1870.
Source: County-level data from the *Statistique Générale de la France*.

Table 9: Long-run results for education and fertility: Women

	Crude Birth Rate (% change 1881-1911)											
Dependent Variable	(1)			(2)			(3)			(4)		
	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$
Female literacy	-0.164***	-0.272***	-0.164***	-0.223**	-0.270***	-0.160**	-0.165**	-0.262***	-0.154**	-0.230***	-0.233***	-0.122*
(% change 1856-70)	(0.027)	(0.061)	(0.068)	(0.069)	(0.061)	(0.079)	(0.076)	(0.059)	(0.066)	(0.071)	(0.056)	(0.070)
Crude birth rate 1851	-0.156***	-0.015***	-0.013***	-0.016***	-0.015***	-0.015***	-0.011*	-0.011***	-0.008**	-0.012*	-0.021***	-0.017***
	(0.003)	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.006)	(0.004)	(0.003)	(0.007)	(0.005)	(0.005)
Female in agriculture	-0.240**	-0.131*	-0.221**	-0.135	-0.132*	-0.241**	0.050	-0.127	-0.216**	-0.123	-0.163*	-0.266***
	(0.075)	(0.078)	(0.074)	(0.101)	(0.079)	(0.076)	(0.101)	(0.079)	(0.075)	(0.101)	(0.088)	(0.077)
Female in industry	0.578***	0.002	0.236	-0.125	0.011	0.598***	-0.057	0.070	0.310*	-0.096	0.027	0.646***
	(0.156)	(0.206)	(0.166)	(0.306)	(0.205)	(0.158)	(0.272)	(0.218)	(0.177)	(0.315)	(0.213)	(0.156)
Urbanization	-1.303	-1.582	-2.358**	-0.289	-1.505	-1.121	1.544	-1.289	-2.049*	-0.333	-0.973	-0.527
	(0.889)	(1.122)	(1.134)	(1.281)	(1.126)	(0.886)	(1.245)	(1.186)	(1.113)	(1.364)	(1.095)	(0.800)
Population density	-0.035	0.034	0.035	-0.028	0.028	-0.049	-0.026	0.012	0.011	-0.0224	-0.019	-0.101
	(0.084)	(0.093)	(0.087)	(0.099)	(0.094)	(0.085)	(0.109)	(0.095)	(0.086)	(0.111)	(0.074)	(0.063)
Share Protestants				-0.003	-0.001	-0.003*	-0.005**	-0.001	-0.0008	-0.002	-0.002	-0.004**
				(0.002)	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)
Life expectancy							0.004	0.005	0.005*	0.007	0.007*	0.009**
							(0.005)	(0.004)	(0.003)	(0.004)	(0.003)	(0.003)
Crude birth rate 1881										-0.004	0.014**	0.013***
										(0.006)	(0.006)	(0.005)
Constant	0.481***	0.348**	0.354***	0.325***	0.346**	0.478***	0.185**	0.128**	0.208**	0.276**	0.112***	0.116
	(0.122)	(0.106)	(0.099)	(0.123)	(0.107)	(0.122)	(0.892)	(0.062)	(0.098)	(0.101)	(0.005)	(0.005)
N	82	82	82	82	82	82	82	82	82	82	82	82
R^2	0.418	0.466	0.404	0.418	0.468	0.429	0.379	0.481	0.423	0.425	0.535	0.489
F	5.61***	23.79***	14.75***	12.48***	23.92***	11.56***	5.96***	23.10***	12.14***	9.071***	17.91***	9.097***

Quantile regressions. Dependent variable: Percentage change in crude birth rate 1881-1911. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Crude birth rate is defined as the number of birth (in 1000 s) over the total population. Female literacy rate is the percentage change in the share of women who signed their wedding contract between 1856 and 1870.
Source: County-level data from the *Statistique Générale de la France*.

In Figures 4 to 6, we have graphically presented full distributional effects of education on fertility transitions. For instance, Figure 5 (containing four graphs) presents how a small change in educational levels for both male and female affects the rate of fertility transition. In these figures, we have only reported 10th, 50th and 90th quantile estimates along with the OLS lines. The blue lines in each graph present the 10th quantile estimates, whereas the green lines represent 90th quantile. Broken red lines are OLS estimates, whereas thick purple lines are median quantile estimates. It is clear from the four graphs that changes in educational status has had discernible effects on fertility transition and that there is clear gender-bias in the estimated effects. To focus on this point, we have additionally estimated the partial effect of education on fertility transition for both men and women. The partial effect at each quantile is given by the formula $\frac{\partial Q_t(F_i|E_i)}{\partial E_i}$ where $i=$ {Male, Female}. Table 10 presents the estimates of these effects based on Tables 4 and 5 (for short-run) and Tables 8 and 9 for long-run. It is clear from the estimates in Table 10 that the magnitude of a decline in fertility in female population is larger than men for all quantiles in the long-run and all quantiles (except 25th) for short-run. Our inter-quantile difference test (F-test values) also point at the significance of difference in results across quantiles.

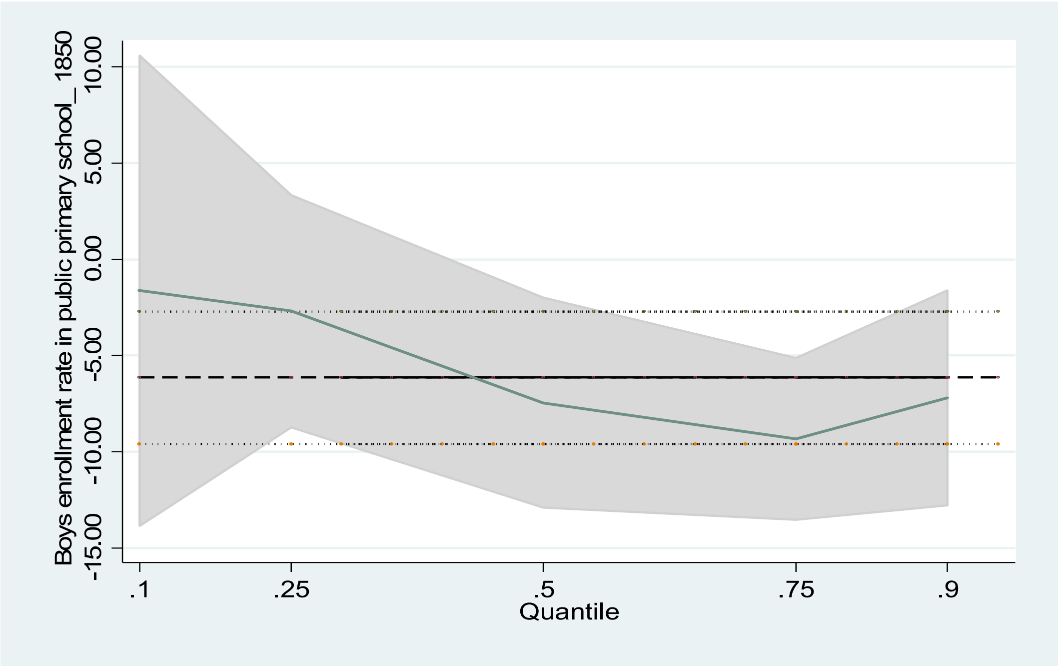
Table 10: Comparison of Partial Effects

	Short-run		**Long-run**	
	Boys	Girls	Boys	Girls
25th Quantile	-6.677	-5.736	-0.075	-0.230
50th Quantile	-6.745	-8.859	-0.204	-0.233
75th Quantile	-7.859	-9.572	-0.002	-0.122
Inter-quantile difference test	$F(2, 81) = 7.352$ ($p = 0.008$)	$F(2,81) = 9.695$ ($p = 0.006$)	$F(2, 80) = 6.109$ ($p = 0.004$)	$F(2,80) = 7.398$ ($p = 0.004$)

Overall, our results indicate that the variations in female endowment in human capital have a robust and significant impact on the fertility transition contrary to male endowment in human capital. This result is consistent with the intuition of the unified growth model of Diebolt and Perrin (2013b) briefly presented in Section 1.2, according to which female endowed with a higher amount of human capital tend to limit their fertility due to a larger opportunity cost of having children than female endowed with lower amount of human capital.

Figure 4: Effect of education on fertility (short-run)

(a) Male



(b) Female

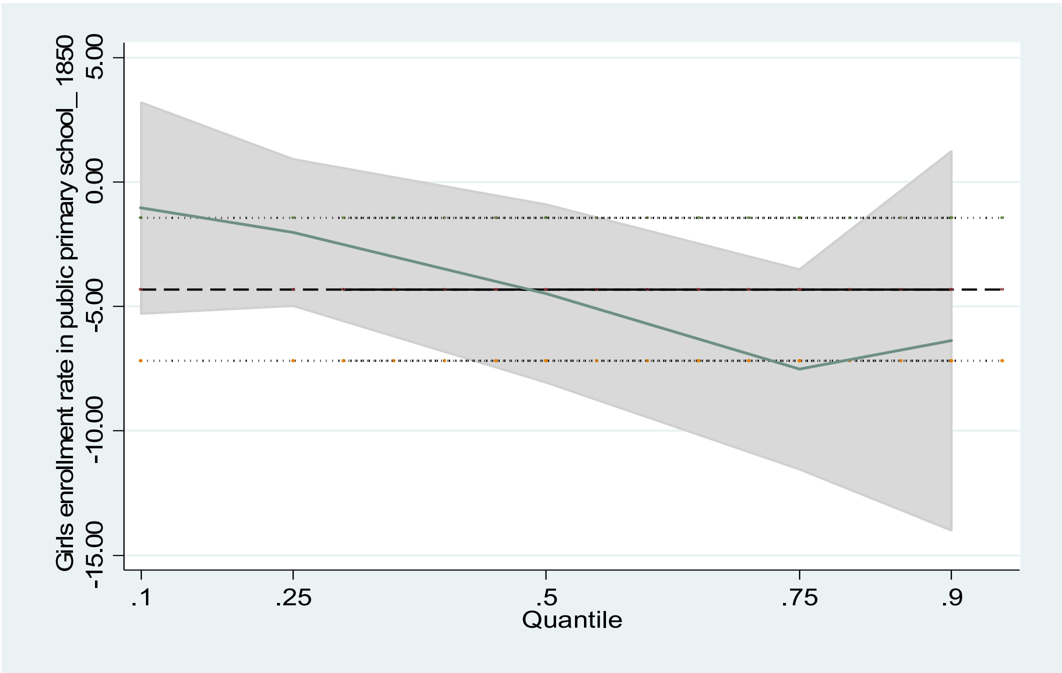
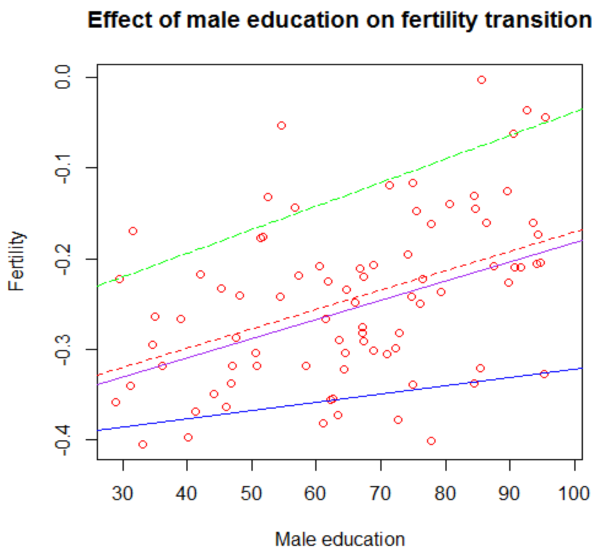
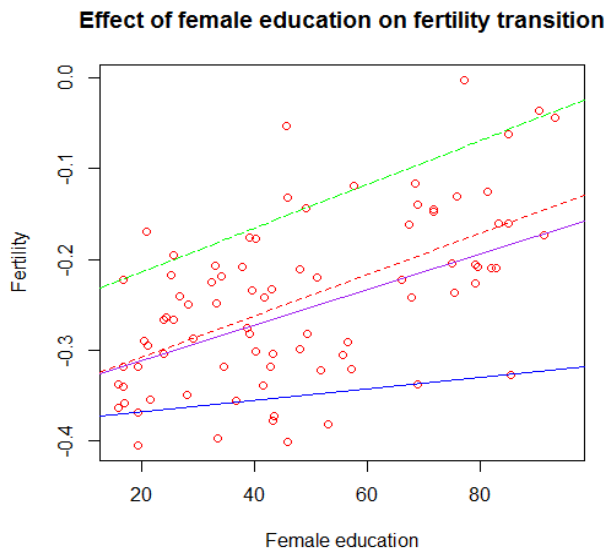


Figure 5: Variation in female education and fertility relationship at various quantiles

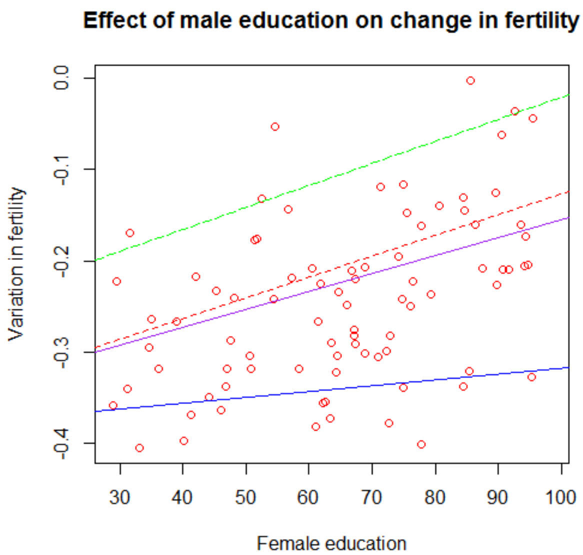
(a) Male



(b) Female



(c) Male



(d) Female

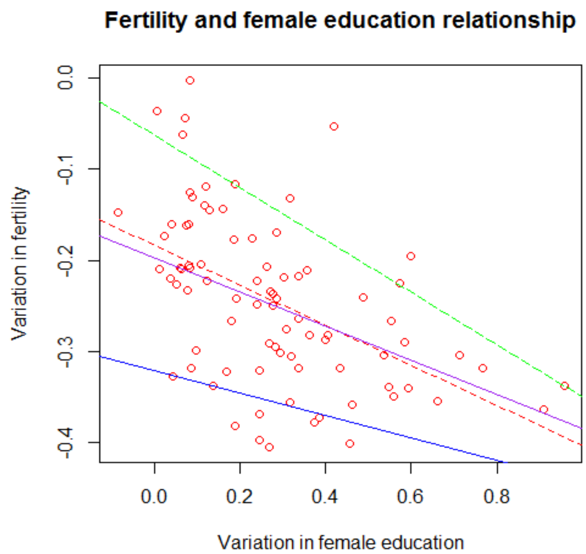
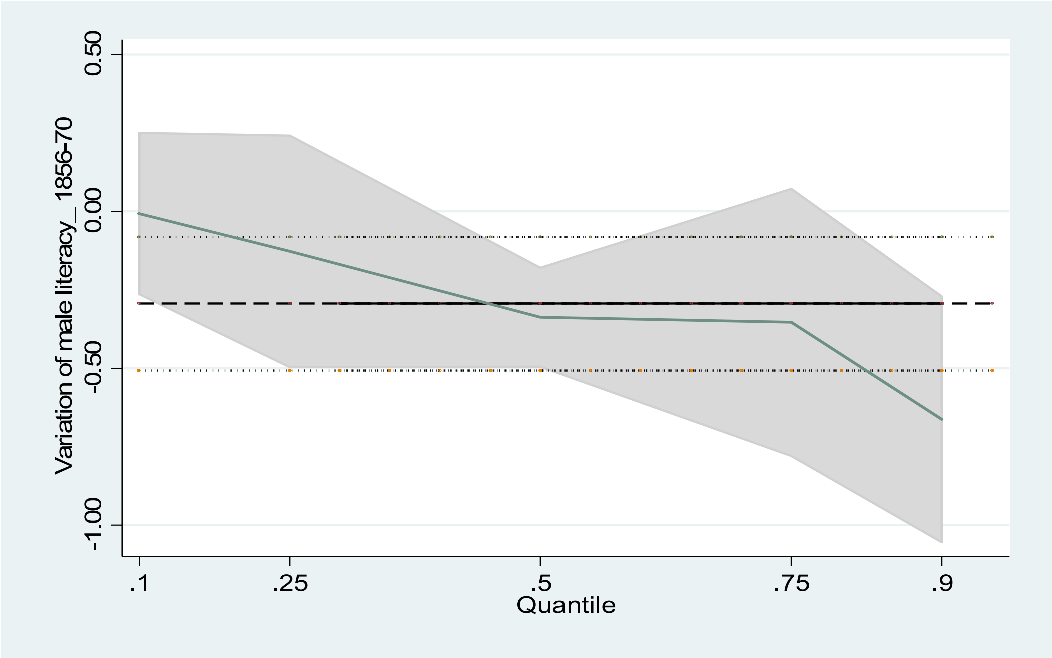
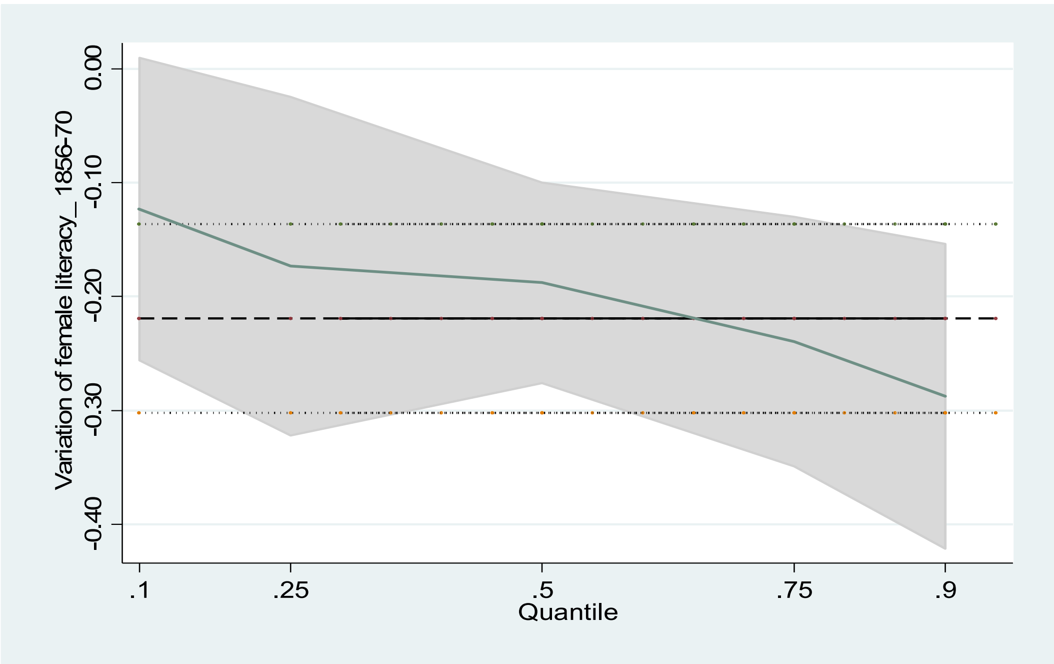


Figure 6: Effect of male human capital on fertility transition: IV Quantile Regression

(a) Male



(b) Female



5.4 Robustness

An additional exercise is to check if our findings of a quantity-quality trade-off, especially the instrumental role of female empowerment are sensitive to the addition of control variables and/or the introduction of alternative dependent variables. As a first step towards achieving this aim, we have re-estimated the education-fertility channel by replacing first the dependent variable. Accordingly, we have replaced crude birth rate with marital fertility rate. Our second strategy is to retain the original dependent variable, crude birth rate but add extra control variables, such as infant mortality, child mortality, male and female wages in agriculture in 1852. Table 11 reports these results. Instead of estimating each set of equations, we have only presented the estimation results for the full model for both men and women. Model 1 reports the results with respect to a change of the dependent variable in the female and male estimations. Model 2 reports the results with additional control variables.

As such, changing dependent variable does not alter our main finding of a negative relationship between fertility and education, although the results appear weaker in magnitudes at low and high quantiles than the one we observed when using the crude birth rate as dependent variable. Moreover, other control variables in this regression setting also present weaker results despite the fact that population density, for instance, indicate negative effect (although insignificant), whereas the positive impact of urbanization is perceived at lower quantile (in case of women). Life-expectancy, as earlier, is significantly negative and indicates that in the face of fertility, reducing effect of life-expectancy, enhancing education reduced fertility. This result is more acute at the lower quantile for women. When we add more control variables, while maintaining crude birth rate as the main dependent variable, the strategy does not improve the results much. The insignificance and weaker results for the effect of education on fertility seem to have been overweighed by likely correlation between these additional variables with education. Instrumentation did not help much. Therefore, this robustness exercise, while pointing at the capital importance of crude birth rate and marital fertility rate as relevant variables for quantity-quality trade-off, need to be pursued with caution concerning the choice of other variables.

Table 11: Robustness of estimates – education and fertility channel: Men and Women

	Men						Women					
Dependent Variable	(1) MFR			(2) CBR			(1) MFR			(2) CBR		
	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$
Enrollment	-0.098**	-0.446*	-0.422***	-0.009	-0.112*	-0.088	-0.159***	-0.432***	-0.560***	-0.012	-0.127*	-0.089
	(0.003)	(0.230)	(0.003)	(0.008)	(0.642)	(0.007)	(0.002)	(0.002)	(0.003)	(0.007)	(0.599)	(0.007)
Employ. in agriculture	0.522	-0.133	0.541	0.535	-0.129	0.512	0.265	0.225	0.061	0.535	-0.157	0.512
	(0.376)	(0.201)	(0.534)	(0.465)	(0.206)	(0.522)	(0.418)	(0.390)	(0.440)	(0.465)	(0.206)	(0.522)
Employ. in industry	-1.296***	0.319	0.330	-0.971	-0.878	0.371	-1.535*	-1.069	-1.307	-0.971	-0.699	0.371
	(0.349)	(0.602)	(0.893)	(1.104)	(0.734)	(0.798)	(0.933)	(0.874)	(0.984)	(1.104)	(0.505)	(0.798)
Urbanization	3.477	3.096	2.531	8.464	12.98***	26.411***	9.159**	6.149	3.819	8.464	14.97***	26.411***
	(5.916)	(2.553)	(2.087)	(5.477)	(2.082)	(9.945)	(4.795)	(4.475))	(5.055)	(5.477)	(3.860)	(9.945)
Population density	-0.124	-0.078	-0.130	-0.211	-1.171**	-0.615**	-0.261**	-0.195**	-0.151	-0.211	-0.985**	-0.615**
	(0.132)	(0.131)	(0.114)	(0.235)	(0.268)	(0.217)	(0.108)	(0.101)	(0.114)	(0.235)	(0.342)	(0.217)
Share Protestants	0.012*	0.007	0.037***	0.010*	0.005	0.023	0.020	0.034**	0.037***	0.009*	0.004	0.023
	(0.005)	(0.005)	(0.012)	(0.015)	(0.005)	(0.012)	(0.023)	(0.011)	(0.012)	(0.015)	(0.005)	(0.012)
Life expectancy	-0.065***	0.0009	-0.099***	-0.075***	-0.021	-0.086*	-0.072***	-0.057***	-0.053***	-0.078***	-0.088*	-0.086*
	(0.011)	(0.008)	(0.015)	(0.013)	(0.045)	(0.049)	(0.014)	(0.013)	(0.015)	(0.013)	(0.038)	(0.049)
Child mortality				15.658	25.145	28.517				17.398	29.233	28.517
				(13.218)	(17.167)	(18.888)				(13.666)	(18.260)	(18.888)
Wage in agriculture				-0.702***	-0.686	-0.056				-0.679***	-0.534*	-0.056
				(0.285)	(0.779)	(0.606)				(0.211)	(0.278)	(0.606)
School				-0.285	-0.554	-1.474***				-0.305	-0.634	-1.474***
				(0.240)	(0.408)	(0.437)				(0.240)	(0.405)	(0.437)
Constant	5.555**	5.616***	7.042***	5.662**	5.616***	10.645***	5.719***	5.751***	5.751***	4.981***	4.660**	10.645***
	(0.781)	(0.726)	(0.838)	(1.104)	(0.726)	(2.660)	(0.791)	(0.834)	(0.834)	(1.104)	(2.390)	(2.660)
N	85	85	85	85	85	85	85	85	85	85	85	85
R^2	0.406	0.454	0.454	0.267	0.483	0.502	0.421	0.409	0.409	0.450	0.493	0.522
F	63.93 ***	35.96***	35.96***	4.55**	14.34**	13.83***	13.17***	11.27***	11.27***	6.38**	16.39**	18.44***

Instrumental variable quantile regressions. Dependent variable: crude birth rate. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Crude birth rate is defined as the number of birth (in 1000 s) over the total population. Girls enrollment rate is the share of girls aged 6-14 enrolled in public primary schools. Column 1 for both boys and girls use marital fertility rate (mfr1851) as a measure of fertility. Whereas column 2 uses CBR as the measure but we include additional controls for robustness check. *Source:* County-level data from the *Statistique Générale de la France*.

6. Conclusion

This paper documents the existence of a quantity-quality trade-off in France during the 19th century. The objective of this paper is twofold: *(i)* investigating both directions of causation of the short-run relationship between education and fertility (i.e. the child quantity-quality trade-off) during the French demographic transition; and *(ii)* studying the long-term effect of endowment in human capital on the subsequent level of fertility. We contribute to the literature of unified growth theory by shedding light on these two types on relationships from a gendered renewed approach.

Using an original county-level dataset of 86 county observations for the year 1851 built up from the *Statistique Générale de la France*, we find in Section 3 evidence of the existence of the child quantity-quality trade-off during the French demographic transition. This result corroborates the predictions and interpretations of the unified growth literature in line with the seminal work of Galor and Weil (2000).

However, this result may hide a more complex relationship linking education and fertility that is the long-run relationship between the female endowment in human capital and the level of fertility, as predicted by Diebolt and Perrin (2013a, 2013b) whose intuitions are briefly presented in Section 1. Hence, using 19th century French data, we have tested in Section 4 the hypothesis that the rise in female endowment in human capital has played a key role in the fertility transition. In line with Diebolt and Perrin (2013b), our results suggest that women with a higher level of human capital have stronger preferences for a lower number of children. In particular, we find the existence of a negative and significant effect of the variations in female literacy rates (1856-70) on the fertility transition between 1881 and 1911. Counties with higher improvements in female literacy display stronger fertility decline in France at the turn of the 19th century.

From our empirical investigation, we find that the quantity-quality trade-off was possibility driven by women endowment in human capital of the previous generation. By extension, as demographic transition is considered necessary condition to allow economies to move from stagnation to sustained growth, female human capital is likely to be a key ingredient for economic transition. Indeed, female empowerment increases returns to education for girls because of complementarities between technological changes and human capital. Girls invest more in their own education and limit their fertility because of a greater opportunity cost of having children. As a consequence, girls with higher endowments in human capital have fewer children what ultimately leads to the fertility transition.

Further research needs to extend this case study to wider panel data investigation to confirm the intuition that women may have been an important factor of economic growth in developed countries and may still be in developing areas.

Appendix – County-level Data for France in the 19th Century

The data used in this paper are mainly extracted from books published by the *Statistique Générale de la France* (SGF) on population, demographic and public education censuses, between 1800 and 1925. Almost all data are available for 86 counties.

Table A: Data Sources and Construction of the Variables

Variable	Year	Definition	Source
Education			
School enrollment rate	1850	Number Number of chikdren enrolled in public primary schools divided by children aged 6-14	*Statistique enseignement primaire and Recensement 1851*
Boys enrollment rate	1850	Number Number of boys enrolled in public primary schools divided by boys aged 6-14	*Statistique enseignement primaire and Recensement 1851*
Girls enrollment rate	1850	Number Number of girls enrolled in public primary schools divided by girls aged 6-14	*Statistique enseignement primaire and Recensement 1851*
Boys schools	1850	Number of public primary schools for boys per number of boys aged 6-14	*Statistique enseignement primaire and Recensement 1851*
Girls schools	1850	Number of public primary schools for girls per number of girls aged 6-14	*Statistique enseignement primaire and Recensement 1851*
Boys enrollment (% change)	1861-67	Variation of boys enrollment rate public primary schools for boys aged 5-15 between 1850 and 1867	*Statistique enseignement primaire and Recensement 1851, 1866*
Girls enrollment (% change)	1851-67	Variation of boys enrollment rate public primary schools for boys aged 5-15 between 1850 and 1867	*Statistique enseignement primaire and Recensement 1851, 1866*
Male literacy (% change)	1856-70	Variation of the share of men who signed their marriage contract between 1856 and 1870	*Statistique enseignement primaire*
Female literacy (% change)	1856-70	Variation of the share of female who signed their marriage contract between 1856 and 1870	*Statistique enseignement primaire*
Distance to Mainz	---	Distance (walk) in km between the main city of the county and Mainz	*http://calculerlesdistances.com/*
Fertility			
Crude birth rate	1851	Number of birth over total population (in thousands)	*Recensement 1851*
Marital fertility rate	1851	Number of new born per married women in age of childbearing (15-45)	*Recensement 1851*
Index of marital fertility rate	1851	Princeton European Fertility Project	*Coale and Watkins (1986)*
Crude birth rate	1881	Number of birth over total population (in thousands)	*Recensement 1881*
Crude birth rate	1881-1911	Variation in the crude birth rate between 1881 and 1911	*Recensement 1881, 1911*
Marital fertility rate	1881-1911	Variation in the marital fertility rate between 1881 and 1911	*Recensement 1881, 1911*
Economic			
Share in industry	1851	Number of people employed in manufacturing	*Recensement 1851*

		per total population	
Share in agriculture	1851	Number of people working in agriculture per total population	*Recensement 1851*
Male in industry	1851	Number of men employed in manufacturing per total population	*Recensement 1851*
Male in agriculture	1851	Number of men working in agriculture per total population	*Recensement 1851*
Female in industry	1851	Number of women employed in manufacturing per total population	*Recensement 1851*
Female in agriculture	1851	Number of women working in agriculture per total population	*Recensement 1851*
Urbanization	1851	Number of towns of more than 2000 inhabitant per km²	*Recensement 1851*
Population density	1851	Number of people per km²	*Recensement 1851*
Male wages in agriculture	1852	Average hourly male wages in agriculture	*Enquête agricole1852*
Female wages in agriculture	1852	Average hourly female wages in agriculture	*Enquête agricol 1852*
Demographic			
Male life expectancy at age 0	1856	Creation of male life tables using population data	*Recensement 1856*
Female life expectancy at age 0	1856	Creation of female life tables using population data	*Recensement 1856*
Share married women	1851	Number of married women per women in age of being married	*Recensement 1851*
Adult sex ratio	1851	Number of female aged 15-45 divided by number of male aged 15-45	*Recensement 1851*
Infant mortality	1851	Mortality quotient at age 0 – Probability to die before celebrating age 5	*Bonneuil (1997)*
Child mortality	1851	Mortality quotient at age 5 – Probability to die before celebrating age 10	*Bonneuil (1997)*
Socio-economic			
Share Protestants	1861	Number of Protestants per 100 people	*Recensement 1861*

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