Education and Polygamy: Evidence from Cameroon *

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Abstract. — Estimating marriage market returns to education and the effect of education on polygamy requires considering the effect of education on men and women separately, and matching on the marriage market. We take advantage of a wave of school constructions in Cameroon after World War II and use variations in school supply at the village level to estimate labor and marriage market returns to education in the 1976 census. Education increases the likelihood to be in a polygamous union for men and for women, as well as the overall socioeconomic status of the spouse. We argue that education increases polygamy for women because it allows them to marry more educated and richer men, who are more likely to be polygamists. To show this, we estimate a structural model of marriage with polygamy. The positive affinity between a man's polygamy and a woman's education turns negative when we take the affinity of education into account.

JEL classification: J12, I20, O12.

Keywords: polygamy, education, marriage, matching models.

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1. Introduction

Education has labor market returns, but also marriage market returns: it affects who you marry, and bargaining power within marriage. This is a particularly crucial question in developing countries, where participation of women in the formal labor market is low, and marriage is an extremely important economic decision in a woman's life. In a number of African countries, where polygamy is still very important, education is likely to not only affect the characteristics of a spouse, but also the number of wives (for men), and the number of co-wives (for women).

Polygamy is still very important in a number of African countries, but it has been declining in recent decades (Fenske, 2015). The expansion of education might have played a role — because of the transmission of different cultural norms by colonial schools and religious missions, because education increased the bargaining power of women, or because education made men more interested in having few educated children rather than many children (Gould et al., 2008). Fenske (2015) studies the effect of historical and current education on a women's likelihood to be polygamous in Africa. He finds that while historical education seems to have decreased polygamy, women exposed to various school construction programs in their youth are not less likely to be polygamous. This is a surprising result as, if education makes women more attractive on the marriage market, we would expect them to be able to be able to marry men with fewer co-wives, even without assuming that education affects culture. Possible explanations could be that the education received is of low quality, or that education does not matter in African marriage markets, though Ashraf et al. (2015) find that, in Zambia, education of the bride is an important determinant of the bride price. Another explanation could be that education affects several characteristics of husbands, the number of co-wives being only one of them, and that other desirable characteristics, like wealth and education, are positively correlated with education. For this reason, it is important to also consider the effect of male education on their likelihood to be polygamists.

Studying marriage market returns to education presents two main challenges. The first one is a classical causal identification problem: the unobservables correlated with education are likely correlated with matrimonial preferences. The second is more specific to the study of marriage markets: the reduced form effect of education on a particular spousal variable (like the number of co-wives) is affected by the effect of education on other variables (like education of the spouse), and the correlation between these variables. Estimating the affinities between various characteristics of husband and wife requires a structural approach.

In this paper, we take advantage of the massive increase in education expenditure in Cameroon after World War II to study the causal impact of education on a variety of labor and marriage market outcomes for men and for women. We use administrative data on the universe of schools in Cameroon with their date of opening, that we geolocate at the school level. We also use the full count of the population census of 1976, geolocated at the village level. We use a difference-in-differences strategy, instrumenting education by the stock of public schools in a village when an individual was of school age, conditional on village and cohort fixed effects, and cohort trends interacted with village characteristics. We find that one additional year of education increases an individual's own labor market prospects and the likelihood to be married (for men but not for women). In the sample of married people, education increases the socioeconomic outcomes of one's spouse (education and formal employment). One additional year of schooling also increases the likelihood to be in a polygamous union by 5 percentage points for men, as well as for women. The result on women might appear counter-intuitive: we argue it is explained by the other dimensions of matching: more educated women marry more educated and richer men, who are also more likely to be polygamists.

To show this, we estimate a model of the marriage market with transfers where men can marry several women. We extend the model of Choo and Siow (2006) to polygamous unions, and borrow the parametrization of the joint utility function of Dupuy and Galichon (2014). This allows us to estimate "affinities" between different characteristics of men and women. These affinities are the second derivatives of the joint utility of the union, and they describe the likelihood that a man with a given characteristic will be matched with a woman of a given characteristic, taking into account the affinity between all other characteristics. We show that the affinity parameters can be recovered by estimating a multinomial logit on pairs of couples within the same village. We use a control function approach to take into account the endogeneity of education.

The assumptions of our model allow us to consider polygamy as a characteristic of the husband. We replicate our reduced form result by estimating a positive affinity between a man's polygamy and a woman's education. When we add the husband's education to the affinity matrix to take into account matching on education, the affinity between a woman's polygamy and a man's education turns negative. This shows matching on education is important to understand the effect of female education on polygamy. While educated women can marry less polygamous men all other things equal, they can also marry richer and more educated men, who are in turn more likely to be polygamous.

We also provide suggestive evidence that the type of schooling matters. While our main specification uses the variation in public schools to obtain exogenous variation in education, we find that women who were exposed to a larger number of private, Christian schools in the village when they were of school age are less likely to be in a polygamous union in 1976. This is consistent with the fact that Christian missions in Cameroon were explicitly fighting polygamy and trying to impose a monogamous model of marriage (Walker-Said, 2015; Tsoata, 1999).

Contributions. Our paper contributes to the literature trying to explain polygamy and its decline. A first group of works tries to explain the existence of polygamous and monogamous societies. Becker (1973) makes the point that the existence of polygamous unions is the equilibrium outcome when there is inequality among males. Boserup (1970) proposed that polygamy was explained by female productivity in agriculture, an idea tested by Jacoby (1995) in Cote d'Ivoire. Dalton and Leung (2014) argue that the greater prevalence of polygamy in West Africa is explained by the effect of the Atlantic slave trade on sex ratios. Other works try to explain the decline of polygamy (or the rise of monogamy): Gould et al. (2008) build a model where economic development explains the decrease in polygamy as men substitute educated children and wives for a large number of children and wives. The only paper trying to estimate the causal relationship between education and polygamy is Fenske (2015), who focuses on women and finds that, while regions that received more colonial government schools and religious missions in the past are less polygamous today, education does not seem to affect female polygamy in a number of recent natural experiments. Our paper also estimates the effect of male education on polygamy, and tries to take explicitly into account assortative matching on education.

We also contribute to the literature on the interplay of labor and marriage market returns to education for women. Goldin (1993) studies the changing meaning of college in the lives of American women over the 20th century. Chiappori et al. (2015) develop a model where education has both marriage market and labor market returns. Few papers focus on developing countries, one exception being Ashraf et al. (2015), who study the role of the bride price custom in explaining whether parents send their daughters to school in response to a school expansion program. In Cameroon, where the majority of ethnic groups have some form of bride price, we find that women's education increases in response to school constructions, that female education has labor market returns (it increases the probability to be employed in the formal sector), and that education matters on the marriage market.

We also contribute to the literature on matching models of the marriage market, particularly the branch of this literature concerned with empirical estimation. Matching models of the marriage market are hard to estimate on data because we do not observe prices. Chiappori et al. (2012) estimate a model where individuals match on a single index aggregating all the characteristics of a mate. Choo and Siow (2006) estimate a model of matching on several discrete attributes of men and women, while Dupuy and Galichon (2014) extent the model to continuous attributes. We extend Choo and Siow (2006) to a setting where men are allowed to marry several women and we show that, for a given distribution of female characteristics and a given joint distribution of male characteristics and their number of spouses, we can identify the second derivatives of the joint utility function of a match with respect to the characteristics of men and women.

In the rest of the paper, we present the data (section 2), the difference-in-differences strategy and the estimated returns to education (section 3), and finally the model of marriage and the results of the structural estimation.

2. Data

In order to identify the effect of education on the marriage market in Cameroon, we use exhaustive geolocated population census data from 1976 and geolocated administrative school data from 2016.

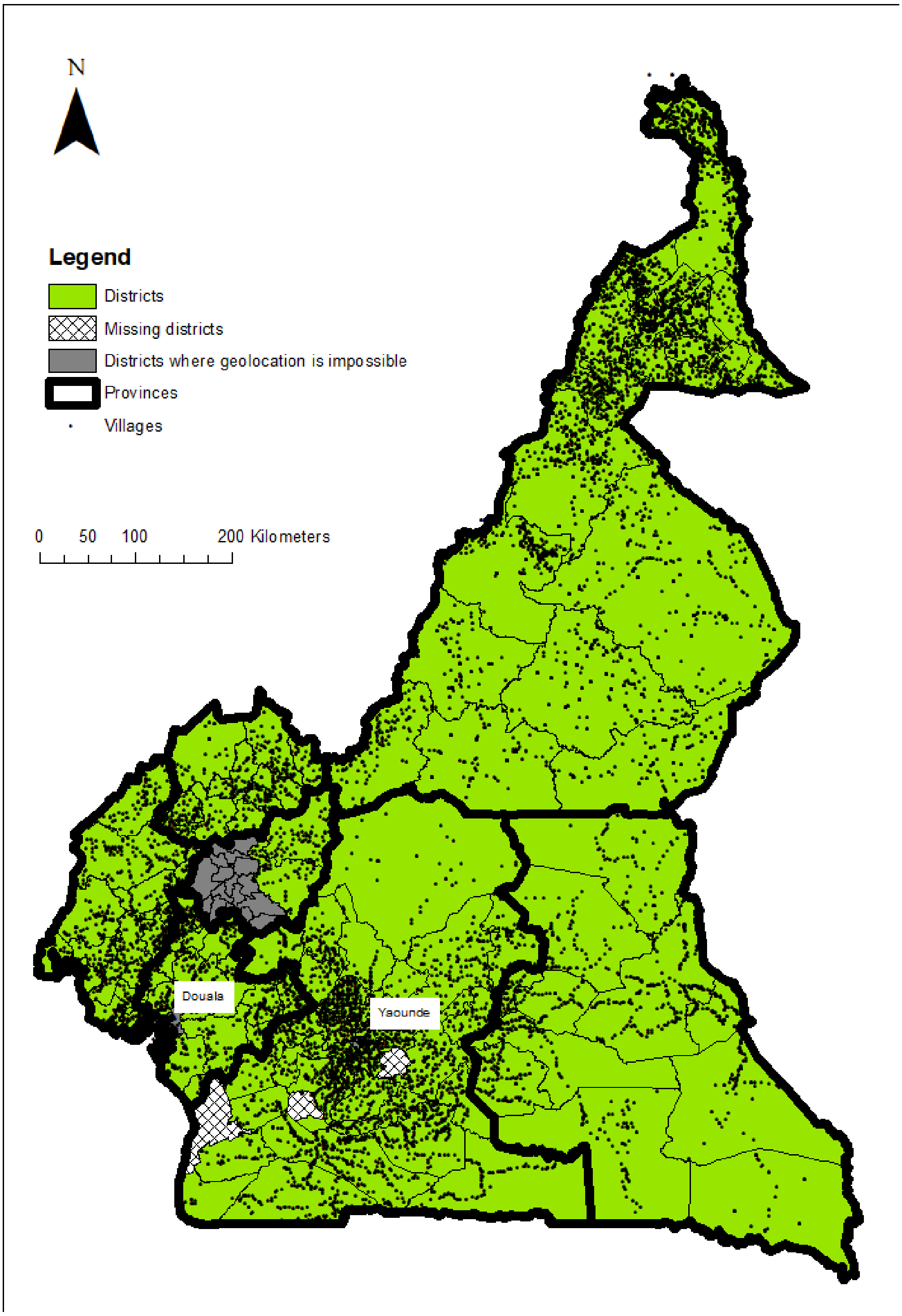
Our main data source is the Cameroonian population census of 1976, for which we have the whole population, except for 3 districts out of 138 that were missing in the raw data.[1] For each individual, the census gives us sex, age (with some imprecision in the form of age heaping), education (last grade attended), marital status (whether an individual is single, divorced, widowed or married — and the number of wives for men), and some very scarce information about occupation.

Our data does not directly gives the line identifier of the spouse for married individuals, but we were able to match spouses living in the same household from information on marital status (including the number of wives for men) and relationship to the household head. In most households, there was no ambiguity about the pairing of spouses (for instance, a household with one household head, two spouses of the household head, one married son of the household and one married other member of the household); however, in large, complex households, we were not always able to match all spouses (for instance when there were several married men and several married women listed as "other household members"). This also means that we were not able to match spouses living in separate households. In the end, we were able to match 91.7% of married women with their husband.

To obtain information on the stock and flow of schools in every village of Cameroon over the 20th century, we use and administrative database of all Cameroonian schools in 2016 with their status (public or private), their date of opening, and the name of the locality. Because this is not historical data, it gives us information about historical school supply insofar as there was no attrition, that is schools, once opened, did not close down. In a period of rapid population growth (Cameroon's population increased sevenfold between 1900 and 2014) and ever-expanding school supply, this seems like a reasonable assumption. To show this, we cross validate our source with historical data for the colonial period. The re-

[1] The districts of Mvengue, Dzeng and Kribi, see figure 1.

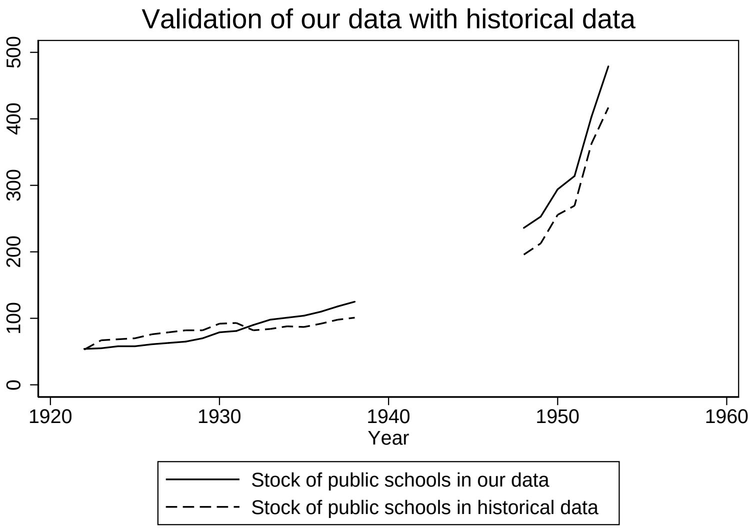
Figure 1: Villages, districts and departements in the 1976 census



Authors' map from 1976 Cameroonian population census data.

ports sent by France and Britain to the League of Nations/United Nations give the total number of schools in Cameroon for the period 1921—1938 and the total number of students for the period 1949–1953.[2] To infer the total number of schools in 1949–1953, we use the average number of students per school in 1938.[3] Figure 2 displays the evolution of the stock of public schools in our data and in historical data. Before 1939, the two curves overlap, though the stock of schools is slightly higher in historical data before 1931, and slightly lower after. Between 1949 and 1953, our data gives more schools than inferred from historical data and the number of students per school in 1938, probably because the number of students per school decreased as more schools were built in rural areas.

Figure 2: Validation of our data with historical data



Sources: Great Britain, Colonial office (1922–1938, 1949–1959); France, Ministère des Colonies (1921–1938, 1947–1957). 1921–1938: the actual number of primary schools is given. 1949–1953: the total number of students is given, we divide by the average number of students per schools in 1938 —124 in French Cameroon and 110 in British Cameroon.

We geolocated villages and schools from each database from the name of the

[2]Sources: Great Britain, Colonial office (1922–1938, 1949–1959); France, Ministère des Colonies (1921–1938, 1947–1957). French reports also give the number of schools in 1921 and 1947, British reports also give the number of students between 1954 and 1959. We only consider years where we have both sources.

[3]Separately for British Cameroon (110) and French Cameroon (124).

locality, using a variety of gazetteers.[4] In the 16 districts of the Bamiléké region, village-level geolocation was impossible, we therefore excluded from our estimations individuals born in these districts.[5] We also excluded from our estimations individuals born in Yaoundé (the administrative capital) and Douala (the economic capital) because of the difficulty to precisely geolocate enumeration areas within these agglomerations.[6] We were able to geolocate 99.9% of the remaining village in the census and 98.3% of individuals — even though we geolocated almost every village, errors in village code entry prevented geolocation for some individuals. Figure 1 maps these villages as well as the districts where geolocation was impossible. We geolocated all 3,765 schools in the administrative school database opened before 1976 from the name of the locality.[7] For 40 schools (1.1%) that could not be geolocated from the name of the locality, we used the centroid of the district.

Finally, we combined both geolocated sources in a GIS software to build the stock and flows of schools (total, public and private) in a radius of 10 km around each village at each date. Figure 3 gives a graphical illustration of the procedure.

The census gives the name of the village of residence and of the district of birth, but not the name of the village of birth.[8] For individuals still residing in their district of birth, we assume that they were schooled in the village in which they were living in 1976. We can therefore, for non-migrants, compute the stock of schools, and the number of school openings at each age. Out-of-district migrants, representing roughly a third of the sample, are excluded from our main specification. Education, our independent variable of interest, is likely to affect

[4]We used the Fallingrain Global Gazetteer (`http://www.fallingrain.com`), the GeoNames geographical database (`http://www.geonames.org`), the website of the Cameroonian Ministry of Energy and Water (`http://www.mng-cameroon.org/SIG/`)) and the Wiki World Map OpenStreetMap (`https://openstreetmap.org`). Geographical information about non-located villages was inferred by taking the mean of located villages in the same canton (a canton is a group of about 10 villages).

[5]Roughly 14% of the population. In the Bamilékés, village codes in the raw data did not match village codes in the locality file. The 16 districts districts are Mbouda, Batcham, Galim, Bafang, Bana, Bandja, Kekem, Dcshang, Penka-Michel, Bafoussam, Bandjoun, Bamendjou, Bangou, Bazou, Tonga and Bangangte.

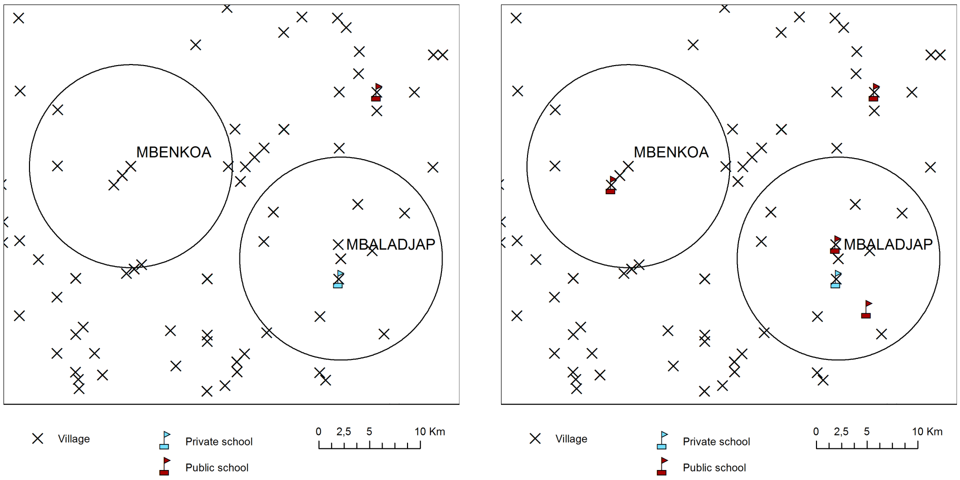
[6]8 districts, corresponding to roughly 5% of the population.

[7]We were able to locate the village 3,333 schools. For 392 schools, we use the location of the town ("ville"), a geographical division larger than the village.

[8]There were 12,125 villages and 138 districts in Cameroon in 1976, see figure 1.

Figure 3: Construction of the school supply variable: example

(a) 1940 (b) 1950



A circle represents a 10-km radius around a given village. In 1940, the village of Mbenkoa has zero schools in a radius of 10 km and the village of Mbaladjap has one (private) school. In 1950, the village of Mbenkoa has 1 (public) school and the village of Mbaladjap has 3 schools (1 private, 2 public).

the decision to migrate: for that reason, we also present results estimated on the full sample (migrants and non-migrants) where education is instrumented by the district average number of available schools for non-migrants (see appendix A.3b).

Table 1 presents some descriptive statistics for the sample of men and women older than 15 in 1976: men have 3 years of education on average, versus 1.4 for women; 17% of men are wage earners, versus only 1% for women. Because of polygyny, the percentage of married men (56%) is lower than the percentage of married women (67%). Married women are on average 10 years younger than their husband. This is important for our identification strategy, because it means that the opening of a school in a village does not necessarily affect both groups of potential mates in the same way (see below). This large average age difference explains why the percentage of widows is much higher among women than men (14% vs 2%). 43% of married women are in a polygamous union, versus 24% of men. 70% of polygamists have 2 wives, 20% have 3 wives and 10% have 4 wives or more. People born before 1940 had on average 0.2 schools in a radius of 10 km around their village when they were 6 (0.1 public and 0.1 private). People born

Table 1: Descriptive statistics

	Women older than 15		Men older than 15	
	Mean	Observations	Mean	Observations
		Full sample		
Age	35.13	1,974,625	35.86	1,754,334
Years of schooling	1.37	1,964,294	2.97	1,747,632
Wage earner	0.01	1,941,572	0.17	1,711,810
Agricultural worker	0.44	1,932,380	0.60	1,530,581
Out-of-district migrant	0.30	1,975,117	0.33	1,754,807
Married	0.67	1,966,349	0.56	1,740,155
Single	0.16	1,966,349	0.39	1,740,155
Widow	0.14	1,966,349	0.02	1,740,155
Divorced	0.03	1,966,349	0.03	1,740,155
		Married sample		
Age	33.12	1,310,614	42.98	975,344
In a polygamous union	0.44	1,184,845	0.24	975,468
# of wives			1.36	970,940
		Sample in a polygamous union		
# of wives			2.46	236,263
2 wives			0.71	236,263
3 wives			0.19	236,263
4 wives or more			0.10	236,263
		Non-migrant sample (excluding Yaounde, Douala, and the Bamilekes)		
Schools in 10-km radius at 6				
born before 1940				
public	0.11	453,701	0.10	464,053
private	0.13	453,701	0.10	464,053
born after 1940				
public	1.36	689,018	1.45	551,207
private	1.19	689,018	1.28	551,207

Sample: all men and women older than 15 in 1976.

after 1940 had on average 1.3 public school and 1 private school.[9]

Appendix figure A.1 gives an idea of the geographical repartition of polygamy. Although there is somewhat of a north/south gradient, polygamy is prevalent in every district. The share of married women in a polygamous union is below 20% only in a handful of districts around the economic capital (Douala) and the administrative capital (Yaoundé).

3. Difference-in-differences estimation

We are interested in estimating the labor market and marriage market returns to education. The endogeneity concerns in estimating labor market returns to education are well known. As for marriage market returns, it is extremely likely that a number of cultural characteristics and personal unobservables determine both educational choices and marriage market outcomes, especially the probability to be in a polygamous union (Fenske, 2015). Like a number of papers following Duflo (2001), we take advantage of an expansion in school supply, the wave of primary school constructions that started in Cameroon after World War II.

3.1. Historical background

After World War I, German Cameroon was divided between the British and the French and administered under mandates of the League of Nations. In both parts, before World War II, public expenditure for education was low and Christian missionaries (Protestant and Catholic) were the main providers of education (Dupraz, 2017). After World War II, education expenditure increased massively in both parts. In British Cameroon, real expenditure per school-age child was increased fourfold between 1937 and 1955. In French Cameroon, it was multiplied by 40 (Dupraz, 2017). As the stated goal of education policy went from educated a small elite to universal primary education, the colonial governments of British and French Cameroon increased subsidies to missionary schools and started building

[9] The slight discrepancy between men and women is due to differences in gender composition across villages explained by different migration patterns: these figures are computed for non-migrant only, and men tend to migrate more than women.

more public schools. School constructions continued after both parts of Cameroon gained independence in 1960 and were reunited in 1961.

Figure 5: Number of yearly school openings in Cameroon, 1900-1976

(a) All schools (b) Public and private schools

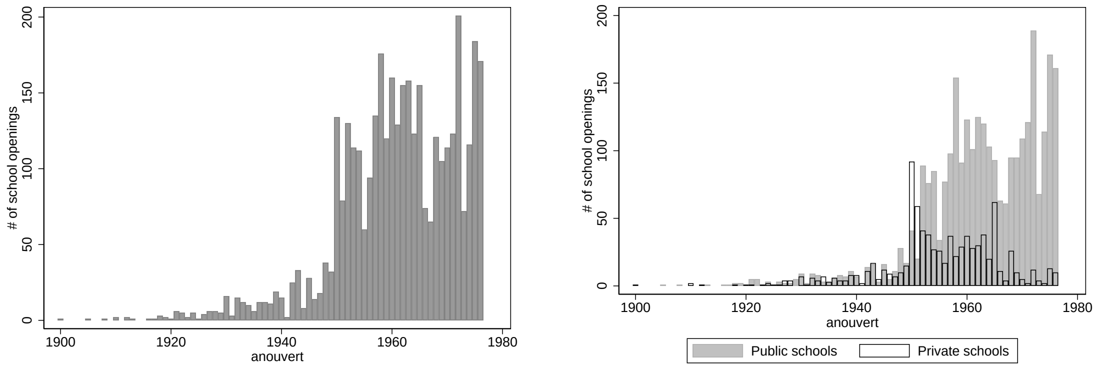


Figure 5 displays the yearly number of school openings in Cameroon for each year between 1900 and 1976 according to our administrative school database. The yearly number of school openings started increasing around 1950, going from an average of 22 from 1930 to 1950 to an average of 114 from 1950 to 1970. As a result, the total number of schools in Cameroon was multiplied by ten from 1945 (286 schools) to 1970 (2800 schools) — appendix figure A.2.

The second panel of figure 5 distinguishes between the flows of public and private (Christian) schools. Though the number of public school openings was higher in almost every year after 1950, the flow of private school constructions intensified as well, as the government was giving increasingly generous subsidies (Dupraz, 2017).

Our analysis will always distinguish between private and public schools. Before the 1980s, private schools in Cameroon were quasi-exclusively Christian schools, and we have every reason to hypothesize that they produced a different kind of schooling and had different effects on the marriage market and polygamy.[10] There is ample evidence that African missions were targeting polygamy specifically and putting a lot of effort in promoting the Christian, monogamous model of marriage.

[10]Non-denominational private schools started opening during the economic crisis of the 1980s in response to the decreasing quality of public schools, while Islamic primary schools are a more recent phenomenon.

Though the French colonial government also sought to change marriage customs, the African clergy was particularly active in criticizing elements of marital customs such as bridewealth and polygamy (Walker-Said, 2015). In Cameroon, Catholic missionaries established "sixas" or "bride schools" to prepare young girls to a Christian wedding (Tsoata, 1999).

3.2. Event study graph

To obtain plausibly exogenous variation in the education of men and women, we use local, village-level variations in the number of schools over time. We motivate our identification strategy by presenting event study graphs displaying the effect of local school openings at different ages. These graphs represent graphically the following equation:

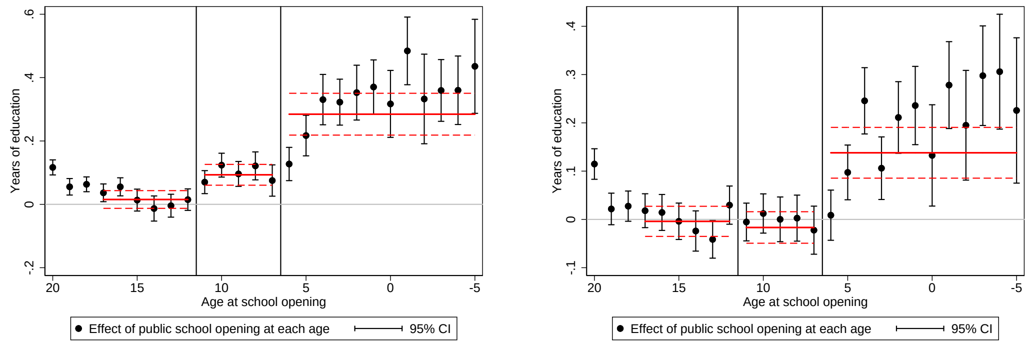
$$E_{ivc} = \alpha_v + \delta_c + \sum_{a=-5}^{a=20} \left(\beta_{public,a} n_{vc}^{public,a} + \beta_{private,a} n_{vc}^{private,a} \right) \tag{1}$$

E_{ivc} is the education (in years) of individual i, born in village v in year c (for cohort). α_v and δ_c are village and cohort fixed effects. $n_{vc}^{public,a}$ is the number of public schools that opened in village v when an individual born in year c was age a (negative numbers are years before birth). $n_{vc}^{public,5}$ is the stock of public schools 5 years before birth. $n_{vc}^{private,a}$ is the same for private schools. For example, for individual i born in 1940 in village v where the only school, public, opened in 1946, $n_{v,1940}^{public,6} = 1$, and all other school opening variables are equal to zero. This equation is estimated separately for men and women. If school openings are driven by exogenous supply rather than by local demand, then, conditional on village and cohort fixed effect, school openings should matter for the education of individuals who were younger than 6. They should not matter for individuals older than 11 who are too old to go to primary school. Because of late school entry, and because the opening of an additional school can alleviate capacity constraints in an existing school, the opening of a school might have an effect between 7 and 11.

Figure 7 displays the β associated with public education. School openings before age 6 are positively correlated with education (one school opening increasing education by about 0.4 years for women and 0.2 for men). School openings between 7 and 11, when children are of school age, are also positively correlated (at least for women), but the magnitude is lower. School openings after 12, when an individual is too old to go to primary school, do not have much of an effect on education (though a couple of coefficients are positive and statistically significant). Appendix figure B.1 displays the β associated with private schools: the picture is similar.

Figure 7: Event study graphs: effect of public school openings on education

(a) Women (b) Men



3.3. Econometric model

In a first stage, we estimate the causal impact of public school construction on education with the following equation:

$$E_{ivc} = \alpha_v + \delta_c + \gamma_1 N_{vc}^{public,6} + \gamma_2 n_{vc}^{public,7-11} + X_{vc}\theta + e_{ivc} \tag{2}$$

$N_{vc}^{public,6}$ is the stock of public schools in the village at 6 (the official school entry age in Cameroon). $n_{vc}^{publi,7-11}$ is the number of public school openings in the village between 7 and 11. It is added as an excluded instrument because late school entry and the alleviation of capacity constraints mean that schools opening between 7 and 11 can still have an effect on education (see event study graphs above). Our results are robust to the use of a single instrument.[11] X_{vc} is a vector of controls at the cohort $\times$ village level (see below).

[11]See appendix table B.1 discussed in section 3.5.

Village fixed effects capture any village characteristic correlated with both education and school constructions. One might be worried, for example, that more schools are built in urban areas where the returns to education are larger. Controlling for village fixed effect will be even more important in the second stage, when we will use marriage market outcomes on the left-hand side. The negative correlation between polygamy and education has been shown to be largely due to geographical controls correlated negatively with education and positively with polygamy (Fenske, 2015). Cohort fixed effects ensure that we will not interpret a spurious correlation between an increasing trend in education (or a declining trend in polygamy) and an increasing trend in school supply.

For γ_1 and γ_2 to identify the causal effect of school construction, we need to assume that, conditional on village and cohort fixed effects, school constructions are uncorrelated with the error term. This is a classic parallel trend assumption. It will be violated if schools are more or less likely to open in villages with a specific trend in education (or marriage market outcomes like polygamy). To alleviate this concern, we control for quadratic trends interacted with village characteristics likely to matter for education and marriage market outcomes: a dummy for belonging to British Cameroon, distance to the closest town in 1922, presence of a mission station in a 25km radius around the village in 1924, the baseline number of public and private schools in 1922.[12] We also show robustness of our results to a specification where X_{vc} contains a vector of cohort fixed effects interacted with province fixed effects (there were seven provinces in Cameroun in 1976, see figure 1).

Though we think our identifying assumption is credible in the case of public schools built in a period of massive extension of primary schooling, it is maybe less credible for private, Christian schools. And indeed, we show below that the parallel trend assumption does not seem to hold for them. For this reason, we do not use private schools as an excluded instrument, but we add the stock of private schools at 6 and the number of private schools built between 7 and 11 as a control in X_{vc}.

[12]Data on the location of town in 1922/1923 is from France, Ministère des Colonies (1922) and Great Britain, Colonial office (1923). Data on the location of mission stations in 1924 is from the Roome map digitized by Nunn (2010).

To provide some evidence that the parallel trend assumption holds, we check that schools built between 12 and 17, when individuals are too old to attend primary school, do not predict education. To do so, we run the following regression

$$\begin{aligned} E_{ivc} &= \alpha_v + \delta_c + \gamma_1 N_{vc}^{public,6} + \gamma_2 n_{vc}^{public,7-11} + \gamma_3 n_{vc}^{public,12-17} \\ &+ \phi_1 N_{vc}^{private,6} + \phi_2 n_{vc}^{private,7-11} + \phi_3 n_{vc}^{private,12-17} + e_{ivc} \end{aligned} \quad (3)$$

$n_{vc}^{public,12-17}$ is the number of public school openings between 12 and 17 and $n_{vc}^{public,12-17}$ is the same for private schools. When $\gamma_3 = 0$, it means that individuals aged 12–17 at the opening of a school are not more educated than in a village where no school opened. This coefficient tests the parallel trend assumption.

The first two columns of table 3 display the coefficients of equation (3) estimated for women and for men. The stock of public schools at 6 is positively correlated with education. An additional public school in the village at 6 is associated with 0.18 additional years of education for women and 0.16 years for men. Private schools have a similar effect, with a coefficient of 0.19 for women and 0.20 for men. The number fo public and private school openings between 7 and 11 is, as expected, positively correlated with education as well, but with a smaller coefficient. Public schools built between 12 and 17, however, have no effect on the education of neither men nor women, which reassures us that the parallel trend assumption holds. Though the number of private school openings between 12 and 17 is not correlated with women's education, it is correlated with men's education (coefficient of 0.03), which might indicate that the parallel trend assumption does not hold in the case of private schools, which are built in villages where the trend in male education is already increasing.

The last two columns of table 3 display reduced form coefficients, that is we estimate equation (3) replacing the left-hand side with a binary variable for being in a polygamous union (given marriage). The number of public schools at 6 is positively correlated with polygamy for both men and women, but not the number of public school openings between 7 and 11. The number of private schools at 6, however, does affect polygamy negatively for women, and has no effect on male polygamy. Given that Christian schools in Africa were fighting polygamy actively

Table 2: Effect of school construction on education and polygamy

	(1)	(2)	(3)	(4)
	years of education		in a polygamous union	
	Women	Men	Women	Men
# public schools at 6	0.1835***	0.1612***	0.0077***	0.0066**
	(0.0329)	(0.0274)	(0.0028)	(0.0032)
# public sch. openings 7-11	0.0491***	0.0374**	0.0017	0.0085***
	(0.0184)	(0.0170)	(0.0019)	(0.0017)
# public sch. openings 12-17	-0.0156	0.0168	-0.0015	0.0013
	(0.0120)	(0.0151)	(0.0017)	(0.0014)
# private schools at 6	0.1933***	0.2005***	-0.0144***	0.0015
	(0.0160)	(0.0194)	(0.0023)	(0.0024)
# private sch. openings 7-11	0.0211	0.1160***	-0.0062**	-0.0015
	(0.0165)	(0.0201)	(0.0025)	(0.0024)
# private sch. openings 12-17	-0.0170	0.0334**	-0.0038*	0.0018
	(0.0122)	(0.0152)	(0.0021)	(0.0020)
Village F.E.	✓	✓	✓	✓
Cohort F.E.	✓	✓	✓	✓
Quadratic trend × village controls	✓	✓	✓	✓
Province specific cohort F.E.				
Observations	700,986	608,454	492,816	473,946

Sample: all non-migrant men/women aged 25-60 in 1976. Standard errors clustered at the village level in parentheses. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

(Walker-Said, 2015; Tsoata, 1999), one natural interpretation of this result is that Christian and secular education have very different effects on the marriage market. Another interpretation is that people who go to private school are different (they might for example be richer, as private schools usually charge a small fee), and that the effect of education on polygamy are heterogeneous. Though the very heterogeneous effects of Christian and private schools on polygamy despite their homogeneous effect on education is an interesting result in itself, in line with what was found by Fenske (2015), we do not push it further, because we find evidence that the parallel assumption does not hold. In particular, the correlation between the number of private school openings between 12 and 17 is slightly negative, and significant at the 10% level, which likely indicates that Christian schools are opening in village where there is already a declining trend in polygamy — maybe because these are already Christianized villages.

We use our first stage to instrument for education in the following equation

$$y_{ivc} = \alpha_v + \delta_c + \tau E_{ivc} + X_{vc}\theta + \nu_{ivc} \tag{4}$$

where y_{ivc} can be an individual's own labor market outcome (like the probability to be a wage earner or work in agriculture) or marriage market outcome (like the probability to be in a polygamous union, or education of the spouse). For the exclusion restriction to be met, the parallel trend assumption is not sufficient: it also must be the case that school constructions affect outcome y_{ivc} only through the own education of individual i. This is particularly important for marriage market outcomes, and especially when we estimate assortative mating on education (does your own education increase the education of your spouse?). Because marriage markets are local, the construction of a school in your village also affects the education of your potential mates. If husbands and wives always had the same age, then we could not disentangle the effect of assortative mating from the effect of school construction on education. In Cameroon around independence, individuals do not typically marry within the same age group — husbands are on average 10 years older than their wives (see table 1). However, it is still the case that the stock of schools when an individual was 6 and the stock of schools available when their potential mates were 6 are very correlated. This is one additional motivation to use a structural model: the model we present and estimate in section 4 below allows us to estimate the affinity between polygamy and education taking into account assortative mating on age.

Selective migrations are another threat to the validity of the exclusion restriction. In equations (2) and (4), $N_{vc}^{public,6}$ is the stock of public schools at age 6 in the village where the person *lives in 1976*. As we know the district of birth of individuals, we can exclude out-of district migrants from the sample (about 30% of men and women). However, if education affects the decision to migrate, then our sample might be selected. To alleviate these concerns, we also present a specification on the full sample, including migrants, with an instrument at the district level.[13]

3.4. Results

We estimate large labor market returns to education: one additional year of schooling increases the likelihood to be employed in the formal sector, especially for men. We also find that education increases the likelihood to be married for men, but not for women. Individuals who had access to schooling when they were kids have more educated spouses, and their spouses are more likely to be employed in the formal sector. Educated men also have younger wives, and they are more likely to be polygamous. Perhaps more surprisingly, education also increases the likelihood to be in a polygamous union for women.

We start by estimating labor market returns to education, as well as the effect of education on the extensive margin of marriage. In table 3, panels A and B (for men and for women), we present both the results of an OLS estimation with cohort and village fixed effects and the results of our 2SLS estimation. Education has large labor market effects. Unfortunately, the census does not give information on income, but it gives information on occupation. Education increases the likelihood to be employed in the formal sector and earn a wage by 2 percentage points for women and 7 percentage points for men, which seems to indicate that labor market returns to education are higher for men (table 3, column 1). Education does not affect the likelihood to have ever been married for women, but it increases it by 5

[13]See appendix table B.2 discussed in section 3.5 below.

percentage points for men. It makes sense in a context where unmarried women are very rare — the rate of never married at age 40 in our sample is 11% for men vs 4% for women. Educated women are 5 percentage points less likely to be widowed, which likely reflects the higher socioeconomic status of their husband. There is no effect on widowhood for men, but widowers are very rare (2% versus 14% for widows, see table 1). Finally, education makes men 1 percentage point less likely to have divorced, while the effect is not statistically significant for women (table 3, column 5).

We then focus on the sample of married individuals (table 4). Education increases the socioeconomic status of a spouse. For women, one additional year of education increases their husband's education by 0.73 years and the likelihood that their husband is a wage earner by 5 percentage points (panel A, columns 1 and 2). For men, one additional year of education increases the average education of their wives by 1.21 years (panel B, column 1). These might be the combined result of matching and the school construction shock affecting the education of potential mates. This is one reason for wanting to estimate assortative mating on education in a structural model that also takes into account matching on age. Additionally, we investigate below the robustness of these results to controlling for the stock of schools 3 years before birth for women and at age 16 for men.

One additional year of schooling increases the likelihood to be in a polygamous union by about 5 percentage points for men, as well as for women (column 3). For men, the result should not be surprising: if education increases the attractiveness of men on the marriage market (if only because of very large labor market returns), then it should allow men to marry more women in a society that allows for polygamy. Even without instrumenting for education, the correlation between education and polygamy conditional on village and cohort fixed effects is positive and statistically significant for men, tough very small (panel B, column 4). In table 5, we investigate further the correlation of polygamy and education for men. Column 1 presents the correlation conditional on village and cohort fixed effects: one additional year of education increases the likelihood to be a polygamist by 0.25 percentage points. In column 2, we control for a house-quality based wealth index. The correlation between education and polygamy seems to be overwhelmingly explained by wealth, as the coefficient on years of education

Table 3: Results of 2sls estimation: labor market and extensive margin of marriage

	(1)	(2)	(3)	(4)	(5)
	Panel A: women				
	Wage earner	Agric. worker	Ever married	Widow	Divorced
	OLS (with cohort and village fixed effects)				
Years of schooling	0.02***	-0.02***	-0.02***	-0.01***	0.00***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	2SLS (quadratic trend interact. w/village ctrls)				
Years of schooling	0.02***	-0.02***	-0.01	-0.05***	-0.01
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
F-Stat of first stage	50.58	49.62	13.09	13.09	13.09
Observations	386,450	386,480	698,736	698,736	698,736
# clusters	7,307	7,289	9,214	9,214	9,214
	Panel B: men				
	Wage earner	Agric. worker	Ever married	Widow	Divorced
	OLS (with cohort and village fixed effects)				
Years of schooling	0.04***	-0.03***	0.01***	-0.00***	-0.00***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	2SLS (quadratic trend interact. w/village ctrls)				
Years of schooling	0.07***	-0.08***	0.05*	-0.00	-0.01**
	(0.03)	(0.02)	(0.02)	(0.00)	(0.00)
F-Stat of first stage	19.93	23.25	17.39	17.39	17.39
Observations	558,430	532,713	604,670	604,670	604,670
# clusters	9,166	9,151	9,201	9,201	9,201

Sample: all non-migrant men/women aged 25-60 in 1976. Standard errors clustered at the village level in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 4: Results of 2sls estimation: sample of married individuals

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: women			
	Husband's education	Husband wage earner	Husband polygamous	Husband's # of wives	Wife rank	Husband's age
			OLS (with cohort and village fixed effects)			
Years of schooling	0.60***	0.03***	-0.01***	-0.02***	-0.03***	-0.54***
	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.02)
			2SLS (quadratic trend interact. w/village ctrls)			
Years of schooling	0.73***	0.05***	0.05**	0.13**	0.05	-0.52
	(0.07)	(0.01)	(0.02)	(0.06)	(0.05)	(0.42)
F-Stat of first stage	17.07	18.36	17.13	17.13	17.01	17.14
Observations	491,152	451,030	490,045	490,045	498,101	491,806
# clusters	9,040	8,985	9,039	9,039	9,074	9,042
			Panel B: men			
	Wife(s)'s education		Polygamous	Number of wives		Wife(s)'s age
			OLS (with cohort and village fixed effects)			
Years of schooling	0.29***		0.00***	0.01***		-0.34***
	(0.00)		(0.00)	(0.00)		(0.01)
			2SLS (quadratic trend interact. w/village ctrls)			
Years of schooling	1.21***		0.05**	0.06		-0.75***
	(0.13)		(0.02)	(0.04)		(0.25)
F-Stat of first stage	15.86		14.37	14.65		15.71
Observations	438,328		472,341	470,247		439,070
# clusters	9,041		9,093	9,091		9,043

Sample: all non-migrant men/women aged 25-60 in 1976. Standard errors clustered at the village level in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

turns negative and marginally significant. Education might have very different effects on polygamy depending on whether it was obtained in a public school or a private Christian school, as Christian misisons were fighting polygamy actively (Walker-Said, 2015; Tsoata, 1999). Unfortunately, the census does not indicate whether education was obtained in a public or a private school. In the last two columns of table 5, we restrict the sample to villages with no private schools, in order to focus solely on secular education. The correlation between education and polygamy becomes three times larger, at 0.71 percentage points (column 3). It is again largely accounted for by wealth (column 3). Finally, figure 9 estimates the likelihood to be in a polygamous as a fully flexible function of years of education in villages with no private schools. The relationship between education and polygamy is hump-shaped. While having only a few years of primary education hardly matters, perhaps because they are not associated with a diploma allowing access to formal employment, men who have exactly 6 years of primary education are 5 percentage points more likely to be polygamous. Men who have attended lower secondary school are about 10 percentage points more likely to have several wives, while the effect decreases for men who attended high school. Men who have 13 years of education or more are no more likely to be polygamists than men with no education. If the takers of our instrument go on to complete primary education but do not go to high school, then it could explain why we estimate such a large effect of one year of education on the likelihood to be in a polygamous union.

The fact that education increases the likelihood to be in a polygamous union for women is more surprising. If education makes women more attractive on the marriage market, and if women prefer to marry men with fewer co-wives, then we would expect education to decrease polygamy for women. But what we estimate with our 2sls strategy is a reduced form result, which is the combined effect of matching on many characteristics. If educated women marry more educated men and educated men are more likely to be polygamous, then our positive reduced form effect might mask a negative affinity between female education and polygamy. In order to explore this possibility, we turn to a structural model of the marriage market in section 4. A structural model also have the advantage of taking matching on age into account.

Table 5: Correlation between education and polygamy for men

	(1)	(2)	(3)	(4)
	Dep. var.: in a polygamous union (given married)			
	All villages		Villages with no private school	
Years of education	0.0025***	-0.0011*	0.0069***	0.0038***
	(0.0006)	(0.0006)	(0.0008)	(0.0008)
Wealth index		0.0991***		0.1035***
		(0.0028)		(0.0040)
Village F.E.	✓	✓	✓	✓
Cohort F.E.	✓	✓	✓	✓
Observations	480,200	470,829	292,704	285,822

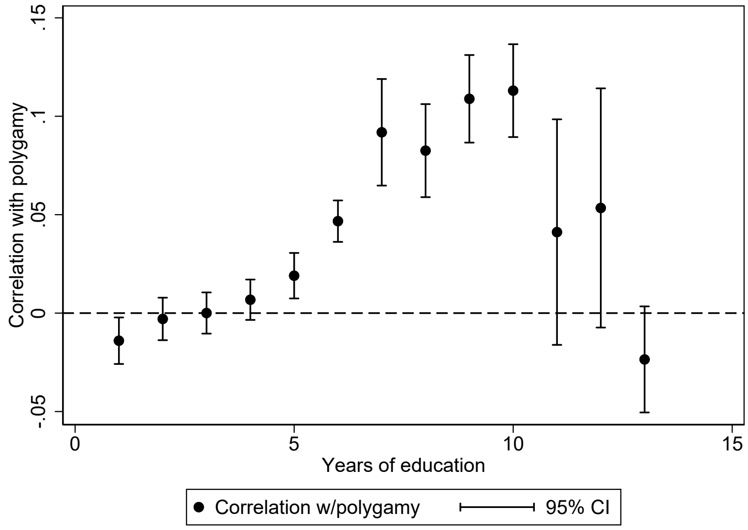
Sample: all non-migrant married men aged 25-60 in 1976. Standard errors clustered at the village level in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

3.5. Robustness

Robustness to different specifications. Appendix table B.1 explores the robustness of our results to various specifications. For women (panel A) and men (panel B), we display the returns to education obtained with 3 different alternative specifications. The first is a simple difference in differences that does not control for time trends interacted with village characteristics. In the second specification, we interact the full vector of cohort fixed effects with a vector of province fixed effects. The third specification is our main specification with a single instrument, the number of schools in the village at age 6.

Results are broadly consistent across specifications with a couple of caveats: the effect of women's education on husband's age are very unstable, and for men, the specification with province specific fixed effects has a very weak first stage, with a F-stat of less than 5. As a result, labor market returns to education are likely overestimated (one additional year of education increases the likelihood to have a formal occupation by 22 percentage points), and the effect of education on the likelihood to be in a polygamous union is also very large (0.17 percentage points), and not statistically significant.

Figure 9: Polygamy as a fully flexible function of years of education in villages with no private school



Migrations. In our main specification, we instrument education by the stock of public schools at age 6 in the village where the individual lives in 1976, excluding people who migrated out of their district of birth (about 30% of the sample). If education affects the decision to migrate, then our sample might be selected. More precisely, we might be worried that the men and women who decide to migrate when they get educated have specific preferences with respect to, for example, polygamy. If women and men with a strong distaste for polygamy migrate when they obtain education, then part of the positive effect of education on polygamy could be explained by migrations. In appendix table B.2, we present the results of a specification where we use as an instrument the district average number of available schools at 6 in the district of birth. More precisely, our first stage becomes

$$E_{idc} = \alpha_d + \delta_c + \gamma_1 \bar{N}_{dc}^{public,6} + \gamma_2 \bar{n}_{dc}^{public,7-11} + X_{dc}\theta + e_{idc} \quad (5)$$

α_d are district fixed effects. $\bar{N}_{dc}^{public,6}$ and $\bar{n}_{dc}^{public,7-11}$ are averages at the district level of variables $N_{vc}^{public,6}$ and $n_{vc}^{public,7-11}$ on the sample of non-migrants. The vector X_{dc} contains district average for the private school supply variables. Standard errors are clustered at the district level. Because the census gives the district of birth of everyone, migrants and non-migrants, we can estimate our model for the sample of non-migrants and for the full sample. This is shown in appendix table B.2. The first thing to note is that an additional year of education greatly increases the likelihood to migrate (by 4 percentage points for women and 13 percentage points for men — column 1). For men and for women, labor market returns are larger when estimated on the full sample than when estimated on the sample of non-migrants alone (column 2). We still estimate a positive effect of education on polygamy when we consider the full sample. For women, the estimated effect is slightly lower on the full sample (3 percentage points vs 5 percentage points), but the two coefficients are not statistically different from each other (panel A, column 5). For men, we estimate very similar effects whether we consider the sample of non-migrants or the full sample (panel B, column 5).

Controlling for the stock of schools when the potential mate was age 6.

4. Structural estimation of marriage market returns to education

According to our difference in differences estimates of returns to education, public education increases a woman's likelihood to be in a polygamous union. But education also increases a husband's education and socio-economic status. Richer men, and more educated men, are more likely to be polygamous. Additionally, there is matching on age, and the educational shock we use to instrument for education also affects the education of potential mates. To disentangle all these effects, we want to estimate marriage market returns to education on a given characteristic of the marriage taking into account all other characteristics of the match. To do so, we consider a matching model of marriage *whose parameters can be estimated on data.* We extend the model of Choo and Siow (2006) to polygamous marriages and we adopt the joint utility parametrization of Dupuy and Galichon (2014). We estimate "affinities" between the characteristics of husbands and wives in a match. These affinities describe the likelihood of observing a match where a husband and a wife have certain attributes (for example, the man is a polygamist, the woman is educated) taking into account the matching between all other attributes.

We show that the strong affinity between a man's polygamy and a wife's education is entirely explained by assortative matching on education. Once education of the husband is added as an attribute, the affinity between male polygamy and female education turns negative. It shows that the private marriage market returns of education on polygamy are negative for women.

4.1. A matching model of the marriage market

In the standard structural model of matching with transferable utility of Choo and Siow (2006) or Dupuy and Galichon (2014), men with a set of attributes x marry women with a set of attributes y. We generalize the model of Choo and Siow (2006) to the polygamous case. In their model, the attributes of men and women are discrete. Dupuy and Galichon (2014) show a generalization to continuous attributes in the monogamous case.

A man m of characteristics $x_m = x$ marrying a set of women $W = \{w_1, \ldots, w_{n_Y}\}$ of characteristics $Y = \{y_1, \ldots, y_{n_Y}\}$ get utility

$$\mathcal{U}(m, W) = U(x, Y) + \varepsilon_{mY} = \sum_{y \in Y} u(x, y, n'_Y) + \varepsilon_{mY} \tag{6}$$

$U(x, Y)$ is the systematic part of the utility, and it assumed to be additively separable in the utility given by each match with a woman of characteristics y. n_Y is the total number of wives, and $n'_Y = n_Y - 1$ is the number of co-wives a given wife has. The utility of a match with a given wife is allowed to depend on the number of co-wives n'_Y. The model has transferable utility: husband and wife can transfer utility to one another to compensate for some characteristics. These utility transfers play the role of prices, but are unobserved by the econometrician.[14] $U(x, Y)$ is the utility post transfers. ε_{mY} is a randomly drawn "sympathy shock" for each set of spouses Y. Each man m is therefore allowed to have idiosyncratic preferences for his wives' characteristics Y, but not preferences for individual women. ε_{mY} follows a Gumbel distribution, and is independent between Y.

A woman w with characteristics $y_w = y$ marries a man m of characteristics

[14]In the context of Cameroon, marriage is associated with an actual price, the bride price, but we do not observe them.

$x_m = x$ with a set of wives $W_m = \{w_{m1}, \ldots, w_{mn_m}\}$ of characteristics $Y_m = \{y_{m1}, \ldots, y_{mn_Y}\}$. She gets utility:

$$\mathcal{V}(m, W', w) = v(x, Y', y) + \eta_{wxn'_Y} \tag{7}$$

$v(x, Y', y)$ is the systematic part of the utility which depends on the characteristics of the man x, of the co-wives Y' and of the woman y.[15] $\eta_{wxn'_Y}$ is a randomly drawn "sympathy shock" of woman w for men of type x with n'_Y co-spouses. η_{wxn_Y} follows a Gumbel distribution and is independent between (x, n'_Y). Each woman w is therefore allowed to have idiosyncratic preferences for the husband's characteristics x and the number of co-wives n'_Y, but *not for the characteristics of the co-wives.* This is the crucial assumption that allows us to extend the model to polygamy. Because $n_{wxn'Y}$ does not depend on the characteristics of co-wives, all women of type y have the same preferences for the characteristics of co-wives Y' (conditional on x and n'_Y). Marriages between a man of characteristics x with n'_Y wives and a woman of type y must all give the same utility $\tilde{v}(x, y, n'_Y) + \eta_{wxn'_Y}$, otherwise all women would prefer one marriage, and there would be no equilibrium. It means that in equilibrium, husbands must fully compensate spouses for the change in utility caused by Y'. Women maximize:

$$\mathcal{V}(m, W', w) = \tilde{v}(x, y, n'_Y) + \eta_{wxn'_Y} \tag{8}$$

Because the sympathy shocks ε_{mY} and $\eta_{wxn'_Y}$ are i.i.d. and follow a Gumbel distribution, the distributions of men's wives $\pi(Y|x)$ and the distribution of women's husbands $\pi(x, n'_Y|y)$ both follow a mulitnomial logit (McFadden, 1974):

$$\pi(Y|x) = \frac{\exp\left(U(x, Y)\right)}{\sum_{Y' \in \mathcal{Y}} \exp\left(U(x, Y')\right)} \tag{9}$$

$$\pi(x, n'_Y|y) = \frac{\exp\left(\tilde{v}(x, y, n_Y)\right)}{\sum_{x' \in \mathcal{X}, n'_Y \in \mathbb{N}} \exp\left(\tilde{v}(x', y, n'_Y)\right)} \tag{10}$$

Equations (9) and (10) are compatible. This is shown by Theorem 1, whose

[15] The set of co-wives of w is denoted $W' = W - \{w\}$, and the matrix of their characteristics is denoted $Y' = Y - \{y\}$.

proof is given in appendix C.

Theorem 1. *For any (implicitly transferable) utility functions following (6) and (7), and for any distribution of female and males attributes, there is an equilibrium following both (9) and (10).*

We now characterize the equilibrium. We can write the probability to be married with a woman of type y and with n_Y other co-spouses:

$$\begin{aligned}\pi(y,n_Y|x) &= \frac{\sum_{Y'\in\mathcal{Y},y\in Y',n'_Y=n_Y+1}\exp\left(U(x,Y')\right)}{\sum_{Y'\in\mathcal{Y}}\exp\left(U(x,Y')\right)}\\ &= \frac{\exp(u(x,y,n_Y))\sum_{Y'\in\mathcal{Y},y\notin Y',n'_Y=n_Y}\exp\left(\sum_{y'\in Y'}u(x,y',n_Y)\right)}{\sum_{Y'\in\mathcal{Y}}\exp\left(U(x,Y')\right)}\end{aligned}$$

We assume that the chances to marry a spouse of type y are small for any number of spouses n_Y. This implies the set of spouses type is large enough. A consequence of this is, for any n_Y:

$$\frac{\sum_{Y'\in\mathcal{Y},y\in Y',n'_Y=n_Y}\exp\left(\sum_{y'\in Y'}u(x,y',n_Y)\right)}{\sum_{Y'\in\mathcal{Y},n'_Y=n_Y}\exp\left(\sum_{y'\in Y'}u(x,y',n_Y)\right)}\approx 0$$

$$\frac{\sum_{Y'\in\mathcal{Y},y\notin Y',n'_Y=n_Y}\exp\left(\sum_{y'\in Y'}u(x,y',n_Y)\right)}{\sum_{Y'\in\mathcal{Y},n'_Y=n_Y}\exp\left(\sum_{y'\in Y'}u(x,y',n_Y)\right)}\approx 1$$

So we can write the number of matches $\pi(x,y,n_Y)$ in two ways, as a function of males' utility and as a function of females' utility. $f(x)$ is the density of x and $g(y)$ is the density of y: $\pi(x,y,n_Y)=f(x)\pi(y,n_Y|x)=g(y)\pi(x,n_Y|y)$

$$\begin{aligned}\pi(x,y,n_Y) &= \exp\left(u(x,y,n_Y)-a(x,n_Y)\right) &(11)\\ &= \exp\left(\tilde{v}(x,y,n_Y)-b(y)\right) &(12)\end{aligned}$$

where $a(x,n_Y)=\log\left(\sum_{Y'\in\mathcal{Y}}\exp\left(U(x,Y')\right)\right)-\log\left(\sum_{Y'\in\mathcal{Y},n'_Y=n_Y}\exp\left(\sum_{y'\in Y'}u(x,y',n_Y)\right)\right)-\log f(x)$ and $b(y)=\log\sum_{(x,n_Y)\in\mathcal{X}\times\mathbb{N}}\exp\left(\tilde{v}(x,y,n_Y)\right)-\log g(y)$.

The square root of the product of (11) and (12) is

$$\pi(x,y,n_Y)=\exp\left(\frac{\Phi(x,y,n_Y)-b(y)-a(x,n_Y)}{2}\right) \qquad (13)$$

where $\Phi(x, y, n_Y) = u(x, y, n_Y) + \tilde{v}(x, y, n_Y)$ is the total systematic utility generated by a match (x, y, n_Y).

Theorem 2, whose proof is given in appendix C, shows that for every distribution of female characteristics and male characteristics and their number of spouses, there is a unique equilibrium following .

Theorem 2. *For every distribution of female types $g(y)$ and for every joint distribution of males types and of their number of spouses $f(x, n_Y)$, there is at most one equilibrium, which is the unique distribution following the density (4.1).*

Observing the distribution of marriages allows identification of the joint utility Φ up to two separatively additive functions. What can be identified here are the second derivatives of Φ with respect to the characteristics of men and women — the number of co-wives is considered as a characteristic of the man. To emphasize this, to emphasize this, Dupuy and Galichon (2014) propose a simple parametrization $\Phi = x'Ay$, where A is a $d_x \times d_y$ matrix (d_x and d_y are respectively the number of attributes of x and y). A is the Hessian of Φ: $\frac{\partial^2 \Phi}{\partial x \partial y} = A$.

We will identify the elements a_{xy} of the affinity matrix A. Let us consider as an example a_{x_E, y_E} the affinity between the education of husband and wife. It is the second derivative of the joint utility of the match with respect to education of the husband and education of the wife. If we assume that education of the wife increases the joint utility of the match, then $a_{x_E, y_E} > 0$ means that the increase in utility brought by the education of the wife is higher in marriages where the husband is educated. Because individual are maximizing, it also means that it is more likely to observe a match between an educated man and an educated woman than a match between an educated man and an uneducated woman.[16] Each affinity takes as given the affinity between all other characteristics of the match.

Only the distribution of marriages is used for identification, and singles do not contribute to the estimation. This is because the multinomial logit framework used by Dupuy and Galichon (2014) and Choo and Siow (2006) imposes independence of irrelevant alternatives (IIA).

[16]If we assume that education of the wife decreases the joint utility, then a positive affinity means that it decreases utility more in marriage where the husband is uneducated. Our model does not allow us to identify the attractiveness of each type of individual on the marriage market.

4.2. Logit estimation of the model on pairs of couples

We propose a new way of estimating this matching model of the marriage market, following Charbonneau's (2014) approach to estimate logit models with two dimensions of fixed effects.

Because in our model, the number of wives can be thought of as a characteristic of the husband, we simplify notations by considering n'_Y as a characteristic in the vector x of husband's characteristics.

Given the independence between the random terms, each match of type (x, y) is equiprobable. This leads to a simple prediction for the probability that man m of type x_m is matched with a woman w of type $y = y_w$:

$$\mathrm{P}(m, w) = \frac{\pi(x_m, y_w)}{N_{x_m} N_{y_w}} = \exp\left(\Phi(x_m, y_w) - a_m - b_w\right) \tag{14}$$

where N_{x_m} and N_{y_w} are respectively the density of men of type x and the density of women of type y. We add some flexibility in the model here, in the sense that a_m and b_w are sets of individual fixed effects, that need not be fully determined by x and y.

We follow the method of Charbonneau (2014) to estimate logit models with two dimensions of fixed effects. Given that woman w is married, the probability for her husband (denoted $h(w)$) to be man m is:

$$\mathrm{P}(h(w) = m) = \frac{\mathrm{P}(m, w)}{\sum_{m'} \mathrm{P}(m', w)} = \frac{\exp\left(\Phi(x_m, y_w) - a_m\right)}{\sum_{m'} \exp\left(\Phi(x_{m'}, y_w) - a_{m'}\right)}$$

And her probability to marry man m given that she's married in a set of men S is:

$$\mathrm{P}(h(w) = m | h(w) \in S) = \frac{\exp\left(\Phi(w_m, y_w) - a_m\right)}{\sum_{m' \in S} \exp\left(\Phi(x_{m'}, y_w) - a_{m'}\right)} \tag{15}$$

Let us now consider a pair of couples, two women $w = 1$ and $w = 2$ whose respective husbands $h(1) = h_1$ and $h(2) = h_2$ are (respectively or not) $m = 1$ and $m = 2$. We are interested in the probability that the couples are $(1, 1)$ and $(2, 2)$

rather than the opposite. This probability writes:

$$\mathrm{P}(h_1 = 1|\{h_1, h_2\} = \{1,2\}) = \frac{\mathrm{P}(h_1 = 1, h_2 = 2)}{\mathrm{P}(h_1 = 1, h_2 = 2) + \mathrm{P}(h_1 = 2, h_2 = 1)} \tag{16}$$

To simplify the notations, let's denote $\Phi_{11} = \Phi(x_1, y_1), \Phi_{12} = \Phi(x_1, y_2)$. From equation (15) and Bayes' rule, we have:

$$\mathrm{P}(h_1 = 1, h_2 = 2) = \frac{\exp\left(\Phi_{11} - a_1\right)}{\sum_{m'} \exp\left(\Phi(x_{m'}, y_1) - a_{m'}\right)} \frac{\exp\left(\Phi_{22} - a_2\right)}{\sum_{m' \neq 1} \exp\left(\Phi(x_{m'}, y_2) - a_{m'}\right)}$$

Similarly, we can write $\mathrm{P}(h_1 = 2, h_2 = 1)$. If we assume that $\frac{\sum_{m' \neq 1} \exp(\Phi(x_{m'}, y_2) - a_{m'})}{\sum_{m' \neq 2} \exp(\Phi(x_{m'}, y_2) - a_{m'})}$ is sufficiently close to 1 (which means that the fact that one particular man is already married hardly affects the overall probability for a woman to get married), then the probability (16) simplifies and we have:

$$\begin{aligned}
\mathrm{P}(h_1 = 1|\{h_1, h_2\} = \{1,2\}) &= \frac{\exp\left(\Phi_{11} + \Phi_{22}\right)}{\exp\left(\Phi_{11} + \Phi_{22}\right) + \exp\left(\Phi_{12} + \Phi_{21}\right)} \\
&= \frac{\exp\left(\Phi_{11} + \Phi_{22} - \Phi_{12} - \Phi_{21}\right)}{1 + \exp\left(\Phi_{11} + \Phi_{22} - \Phi_{12} - \Phi_{21}\right)}
\end{aligned}$$

The probability $\mathrm{P}(h_1 = 1|\{h_1, h_2\} = \{1,2\})$ follows a logit form. There is no incidental parameter problem, as the fixed effects simplify from the equation. This probability respects the property of independence of irrelevant alternatives, as usual in logit models. Equation (17) is easy to interpret: the allocation $(h_1 = 1, h_2 = 2)$ is relatively more likely than the allocation $(h_1 = 2, h_2 = 1)$ when $\Phi_{11} + \Phi_{22} > \Phi_{12} + \Phi_{21}$, that is the sum of the systematic utilities of matches is higher when woman 1 is married with man 1 and woman 2 with man 2.

We adopt parametrization $\Phi(x, y) = x'Ay$ and apply it to equation (17), which gives, after simplification:

$$\mathrm{P}(h_1 = 1|\{h_1, h_2\} = \{1,2\}) = \frac{\exp\left((x_1 - x_2)'A(y_1 - y_2)\right)}{1 + \exp\left((x_1 - x_2)'A(y_1 - y_2)\right)} \tag{17}$$

To estimate the affinity matrix A, we compute the sum of the log-likelihoods defined by (17) over a sample of potential pairs of couples — hence we estimate the affinity matrix by maximum of pseudo-likelihood. Our dataset contains about $500,000$ couples: considering every possible pair of couples would mean considering more than 10^{11} potential pairs, which is not feasible. In each village, we randomly divide all couples into clusters of roughly 5 and we consider every possible pair of couples within each cluster (10 pairs of couples per cluster).

The logit in equation (17) has no constant: when $x_1 = x_2$ or $y_1 = y_2$, $(h_1 = 1, h_2 = 2)$ is as likely as $(h_1 = 2, h_2 = 1)$ (for the econometrician). The dependent variable of the logit is always 1, as man 1 is always the husband of woman 1. So the model is identified when the matching is imperfect. For example, assume education is the only dimension of x and y. If the assortative matching on education was perfect (the more educated man is always with the more educated woman), then $x_1 - x_2$ and $y_1 - y_2$ would always share the same sign, and increasing A would always increase the likelihood. However, if the matching is imperfect, there are some couples for which $x_1 - x_2$ and $y_1 - y_2$ have different signs, so that increasing A decreases the likelihood for these couples.

4.3. Endogeneity of education

Our structural model allows us to estimate the "affinity" between a certain number of characteristics of wives and husband. These characteristics are education, age, and, for the husband, whether he is a polygamist. For the education characteristic, we are interested in the exogenous part of education, the one that we instrument using the school supply in the village when the individual was of schooling age.

In order to take into account the endogeneity of education, we use a two-step control function approach. Rivers and Vuong (1988) prove the consistency of the control function approaches in the probit case. We are not aware of any paper focusing on logit endogenous variables, but Wooldridge (2015) discusses control function approaches in econometrics along a large class of models, including non-linear dependent variables in general. In this case, control function approaches require independence between the distribution of the error terms and of the instruments.

In a first step, we estimate:

$$\begin{aligned}\Delta E_{wjv} &= \beta_1 \Delta A_{wjv} + \beta_2 \Delta A^2_{wjv} + \gamma_1 \Delta N^{public,6}_{wjv} + \gamma_2 \Delta n^{public,7-11}_{wjv} \\ &+ \Delta A_{wjv} X_v \theta_1 + \Delta A^2_{wjv} X_v \theta_2 \\ &+ \phi_1 \Delta N^{private,6}_{wjv} + \phi_2 \Delta n^{private,7-11}_{wjv} + \Delta e_{wjv} \qquad (18)\end{aligned}$$

$\Delta E_{wjv} = E_{1jv} - E_{2jv}$ is the difference in female education for couple pair j in village v, ΔA_{wjv} is the difference in age and ΔA^2_{wjv} the difference in age squared, $\Delta N^{public,6}_{wjv}$ is the difference in the number of public schools in the village at 6, and $\Delta n^{public,7-11}_{wjv}$ the difference in the number of school openings between 7 and 11 (and the same for private schools). We also interact the polynomial in age difference with a vector X_v of village characteristics.[17] This equation is intended to be as close as possible to the first stage in equation 2, with a couple of caveats: there are no village fixed effects because we consider only pairs of couples within the same village. There are no cohort fixed effects either: because we consider the interactions between all characteristics of the wife and husbands, adding cohort fixed effects would require estimating thousands of additional coefficients (we consider 35 different cohorts). Cohort fixed effects are replaced by a quadratic function of age.[18]

We estimate a similar first-step equation for men:

$$\begin{aligned}\Delta E_{mjv} &= \beta_1 \Delta A_{mjv} + \beta_2 \Delta A^2_{mjv} + \gamma_1 \Delta N^{public,6}_{mjv} + \gamma_2 \Delta n^{public,7-11}_{mjv} \\ &+ \Delta P_{mjv} + \Delta A_{mjv} X_v \theta_1 + \Delta A^2_{mjv} X_v \theta_2 \\ &+ \phi_1 \Delta N^{private,6}_{wjv} + \phi_2 \Delta n^{private,7-11}_{wjv} + \Delta e_{wjv} \qquad (19)\end{aligned}$$

$\Delta P_{mjv} = P_{1jv} - P_{2jv}$ is the difference between a dummy equal to 1 if husband 1 is a polygamist and a dummy equal to 1 if husband 2 is a polygamist.

In a second step, when estimating equation (17), we add to the vectors of characteristics for men and women the residuals of equations (18) and (19), $\Delta \hat{e}_w$ and

[17] Like in equation 2: a dummy for belonging to British Cameroon, distance to the closest town in 1922, presence of a mission station in a 25km radius around the village in 1924, the baseline number of public and private schools in 1922.

[18] We checked that replacing cohort fixed effects by a quadratic in age gave similar results in the difference in differences estimation.

$\Delta\hat{e}_m$.

Finally, the precision of the estimated matrix A must take into account the two-stage procedure. The precision of A is estimated with the hessian of the joint log-likelihood

$$l_j = \log\left\{\Lambda[\Delta x'_j A\Delta y_j]\ \varphi(\hat{e}^2_{mj}/\hat{\sigma}^2_m)\ \varphi(\hat{e}^2_{wj}/\hat{\sigma}^2_w)\right\}$$

where φ is the density of the normal distribution; $\hat{\sigma}^2_m$ and $\hat{\sigma}^2_w$ are the estimated variances of $\hat{e}^2_m$ and $\hat{e}^2_w$. In practice, the maximum of the joint log-likelihood is the same as the result of the two-step procedure. Standard errors are clustered by village.

4.4. Results

We estimate a matrix A of affinity parameters between characteristics of husbands and wives. The matrix A is d_x by d_y where d_x is the number of male attributes and d_y is the number of female attributes. Element a_{ij} of A is the affinity between husband's attribute x_i and wife's attribute y_j. It is is the second derivative of the joint utility of a match with respect to x_i and y_j.

We first try to replicate in this structural framework the positive effect of education on the likelihood for women to be in a polygamous union. To do so, we estimate the affinity between male polygamy and female education, without taking into account the affinity between male and female education. More precisely, we estimate the following equation:

$$\mathrm{P}_j = \Lambda\left[\Delta x'_j A\Delta y_j\right]$$

$\Delta x'_j = \Delta P_{mj} = P_{1j} - P_{2j}$ is the difference in polygamy between husband 1 and husband 2. Δy_j is a vector containing all the Δ variables in the first step equation (18), as well as the residual $\Delta\hat{e}_w$ (the control function).

The first column of table 6 displays the affinity between husband polygamy and wife education. As expected, the affinity is positive when we do not take into account the affinity between education. In column (2), we simply add to the vector of husbands' characteristics Δx_j the difference in age ΔA_{mj} and the difference in age squared ΔA^2_{mj}, in order to take into account matching on age. It does not

Table 6: Estimation of the matrix A

	(1)	(2)	(3)
Hus. polygamous * wife educ	0.20***	0.20**	-0.27**
	(0.07)	(0.09)	(0.11)
Hus. polygamous * wife educ control fct.	-0.06***	-0.00	0.00
	(0.00)	(0.01)	(0.01)
Hus. educ * wife educ.			8.00***
			(1.01)
Hus. educ * wife educ control fct.			0.03
			(0.05)
Hus. educ control fct. * wife educ			-0.04
			(0.03)
Hus. educ control fct. * wife educ control fct.			0.06***
			(0.00)
Wife cohort quadratic * husband charact.	✓	✓	✓
Wife cohort quadratic * village variables * husband characteristics	✓	✓	✓
Hus. cohort quadratic * wife charact.		✓	✓
hus. cohort quadratic * village variables * husband characteristics			✓
Observations	855,579	855,507	853,628

Standard errors clustered at the village level in parentheses. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$. In all regressions, the matrix A includes affinities between the the number of private schools when the husband was 6 and wife characteristics, the number of private schools openings when the husband was between 7 and 11 and wife characteristics, the number of private schools when the wife was 6 and husband characteristics, the number of private schools openings when the wife was between 7 and 11 and husband characteristics.

affect the affinity between polygamy and wife education.[19]

Lastly, we add to the vector of husbands' characteristics Δx_j all the Δ variables in equation (19) and the residual $\Delta \hat{e}_w$ (the control function). Doing so, we take into account the matching between education of the husband and education of the wife. The wife's vector contains 18 characteristics and the husband's vector 19, so we estimate a total of 342 affinity parameters, most of which have no meaningful interpretation, as their role is to make the first step of the control function approach as close as possible to the first stage of our 2sls estimation. In column (3) of table 6, we only present the meaningful affinity parameters. We estimate a very strong affinity between husband and wife education. This very strong affinity is enough to make the affinity between husband polygamy and wife education change sign. This

[19]It does decrease the affinity between husband polygamy and the control function for wife's education, but this affinity does not have a clear interpretation.

means the positive affinity between polygamy and female education was entirely explained by assortative matching on education. Once we properly account for the affinity between the education of husband and wife, we estimate negative returns of education on the likelihood to be in a polygamous union for women.

5. Conclusion

What are the implications of our results for the broader question of the impact of education on African marriage markets and polygamy in the long run? Did the expansion of education matter for the decline in polygamy? Unfortunately, we cannot answer this question directly without making strong assumptions on the mechanisms behind our results.

The important finding is that one cannot immediately infer marriage market returns to education from the reduced form effects of an educational shock. We do find that women use their education on the marriage market to marry men with fewer co-wives, but they also use it to marry men with better socioeconomic characteristics, who are more likely to be polygamous. This might explain the difference in Fenske (2015) between the conditional correlation results, which compare different marriage markets, and the natural experiment results, which, like our results, compare within the same marriage market women who received different education shocks.

However, it is hard to infer from our result the general equilibrium effects of education on polygamy. This will depend on who receives education: men or women? Everybody, or only part of the population? If education makes women more attractive on the marriage market but all women receive education, then, even if women use their education to marry monogamous men, the overall level of polygamy need not change as all women become more attractive at the same time. But our results are also compatible with a model where education empowers women, allowing them to express a distaste for polygamy that they were not able to express before, perhaps because their father were deciding who they were going to marry, like in Tertilt (2006). In that case, educating all women might result in an overall decline in polygamy.

We also find that the type of education matters, in line with Fenske (2015) who finds that the proximity to a historical Christian mission decreases polygamy. In Cameroon, we find suggestive evidence that the opening of a private Christian school and the opening of a public school had drastically different effects on polygamy. This points towards cultural change and religious conversion as an important channel for explainign the decline in African polygamy.

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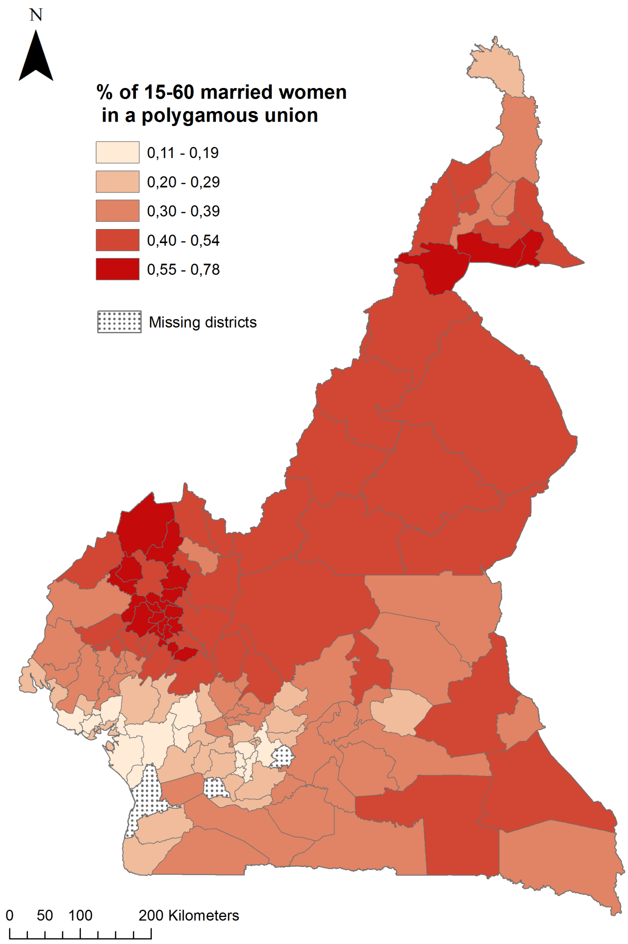
Appendix

A. Additional descriptive statistics

Figure A.1: Share of married women aged 15–60 in a polygamous union in 1976

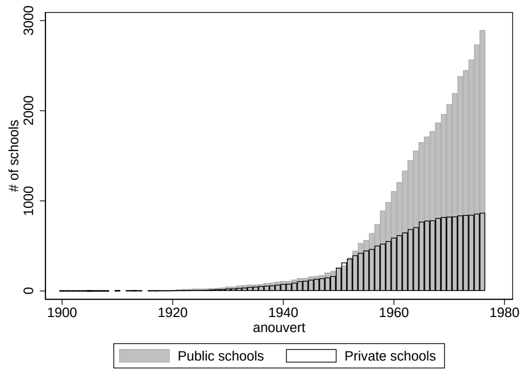


Authors' map from 1976 Cameroonian population census data.

Figure A.2: Total stock of schools in Cameroon, 1900-1976

(a) All schools

(b) Public and private schools



B. Additional results

Figure B.1: Event study graphs: effect of private school openings on education

(a) Women (b) Men

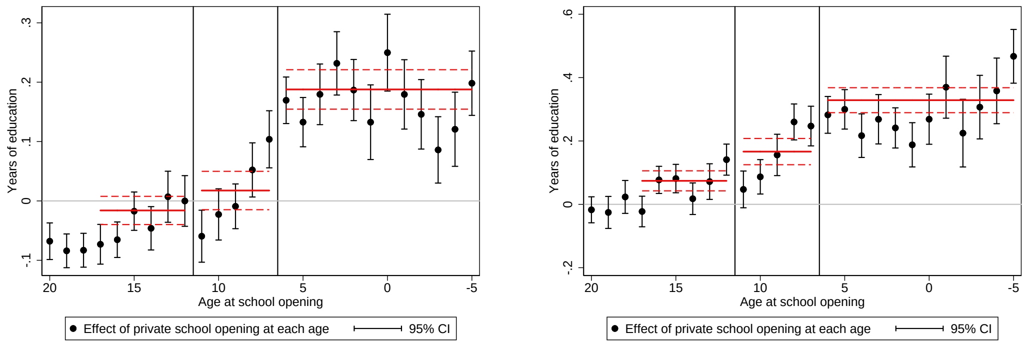


Table B.1: Robustness of 2sls results

	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: women					
	Wage earner	Ever married	Husband's education	Husband polygamous	Husband's # of wives	Husband's age
	2SLS (simple diff in diff)					
Years of schooling	0.02***	-0.01	0.60***	0.06***	0.19***	0.30
	(0.00)	(0.01)	(0.05)	(0.02)	(0.05)	(0.28)
F-Stat of first stage	101.54	31.47	37.24	37.60	37.60	37.44
	2SLS (province specific cohort F.E.)					
Years of schooling	0.03***	-0.00	0.58***	0.08***	0.22***	-1.57**
	(0.01)	(0.01)	(0.11)	(0.03)	(0.08)	(0.61)
F-Stat of first stage	35.67	31.58	40.95	40.85	40.85	40.87
	2SLS (only one excluded instrument)					
Years of schooling	0.02***	-0.02*	0.78***	0.05**	0.13**	-0.08
	(0.01)	(0.01)	(0.07)	(0.02)	(0.05)	(0.42)
F-Stat of first stage	89.36	24.90	32.02	32.10	32.10	32.15
Observations	386,450	698,736	491,152	490,045	490,045	491,806
# clusters	7,307	9,214	9,040	9,039	9,039	9,042
	Panel B: men					
	Wage earner	Ever married	Wife(s)'s education	Polygamous	Number of wives	Wife(s)'s age
	2SLS (simple diff in diff)					
Years of schooling	0.09***	0.07***	1.56***	0.08***	0.10**	-2.04***
	(0.03)	(0.03)	(0.17)	(0.03)	(0.05)	(0.32)
F-Stat of first stage	23.59	17.31	20.56	19.00	19.48	20.32
	2SLS (province specific cohort F.E.)					
Years of schooling	0.22***	0.10	1.76***	0.17	0.17	0.16
	(0.06)	(0.08)	(0.66)	(0.14)	(0.19)	(0.75)
F-Stat of first stage	4.31	4.98	2.99	2.29	2.23	2.93
	2SLS (only one excluded instrument)					
Years of schooling	0.08***	0.03	1.16***	0.04	0.04	-1.03***
	(0.03)	(0.02)	(0.12)	(0.02)	(0.04)	(0.24)
F-Stat of first stage	45.68	39.36	35.46	32.41	32.90	35.10
Observations	558,430	604,670	438,328	472,341	470,247	439,070
# clusters	9,166	9,201	9,041	9,093	9,091	9,043

Sample: all non-migrant men/women aged 25-60 in 1976. Standard errors clustered at the village level in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table B.2: 2sls results: district-level instrument

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Panel A: women						
	Migrant	Wage earner	Ever married	Husband's education	Husband polygamous	Husband's # of wives	Husband's age
	2SLS on the sample of non-migrants						
Years of schooling		0.02***	-0.02**	0.60***	0.05***	0.18***	0.38
		(0.01)	(0.01)	(0.11)	(0.02)	(0.06)	(0.46)
F-Stat of first stage		15.63	13.12	8.82	8.84	8.84	8.81
Observations		395,097	712,033	500,333	499,221	499,221	501,012
# clusters		112	112	112	112	112	112
	2SLS on the full sample						
Years of schooling	0.04***	0.04***	-0.02***	0.71***	0.03**	0.11***	0.16
	(0.01)	(0.01)	(0.01)	(0.06)	(0.01)	(0.03)	(0.22)
F-Stat of first stage	20.92	26.09	20.85	16.93	16.94	16.94	16.92
Observations	979,715	513,164	976,474	681,608	680,232	680,232	682,627
# clusters	112	112	112	112	112	112	112
	Panel B: men						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Migrant	Wage earner	Ever married	Wife(s)'s education	Polygamous	Number of wives	Wife(s)'s age
	2SLS on the sample of non-migrants						
Years of schooling		0.06***	0.07	1.58***	0.08	0.11	-2.65***
		(0.02)	(0.05)	(0.37)	(0.05)	(0.08)	(0.77)
F-Stat of first stage		5.69	5.18	4.15	4.24	4.21	4.19
Observations		568,780	616,151	446,824	481,443	479,319	447,581
# clusters		112	112	112	112	112	112
	2SLS on the full sample						
Years of schooling	0.13***	0.09***	0.05	1.49***	0.07*	0.11*	-2.07***
	(0.03)	(0.02)	(0.03)	(0.27)	(0.04)	(0.06)	(0.58)
F-Stat of first stage	6.35	6.08	6.26	4.94	4.58	4.56	4.97
Observations	869,901	788,595	863,775	600,150	657,394	654,568	601,254
# clusters	112	112	112	112	112	112	112

Sample: all men/women aged 25-60 in 1976. Standard errors clustered at the village level in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

C. Mathematical appendix

C.1. Proof of Theorem 1

This proof requires a few notations. For any transferable utility functions following (6) and (7), let us define:

$$\begin{cases} u(x,y,n) = u_0(x,y,n) - \tau(x,y,n) \\ v(x,y,n) = v_0(x,y,n) + \tau(x,y,n) \end{cases} \tag{20}$$

where $\tau(x,y,n)$ is the (positive or negative) utility transfer given by the man to his wife of type y. $\pi_m(x,y,n) = f(x)\pi(y,n|x)$ is the number of men of type x who want to marry a woman of type y with n co-spouses; similarly, $\pi_w(x,y,n) = g(y)\pi(x,n|y)$ is the number of women of type y who want to marry a man of type x with n co-spouses. There is an equilibrium when $\pi_m(x,y,n) - \pi_w(x,y,n) = 0$. $\pi_m(x,y,n)$ and $\pi_w(x,y,n)$ are continuous functions of $\tau(x,y,n)$. Besides, for every (x,n,y):

$$\begin{cases} \lim_{\tau(x,y,n)\to+\infty} \pi_m(x,y,n) - \pi_w(x,y,n) = 0 - g(y) \\ \lim_{\tau(x,y,n)\to-\infty} \pi_m(x,y,n) - \pi_w(x,y,n) = f(x) - 0 \end{cases} \tag{21}$$

Thus, the generalization of the intermediate values theorem to the multidimensional case, the Poincaré-Miranda theorem, proves there is a solution to the problem $pi_m - pi_w = 0$. (Technically, the Poincaré-Miranda theorem applies only to bounded sets. However, changing the variable to $\tau' = tanh^{-1}(\tau)$ trivially solves this issue.)

C.2. Proof of Theorem 2

This proof follows two steps: the first step explains why equation (4.1) is necessary to have an equilibrium. It requires only a recall of a few elements from the main text. The second part explains why equation (4.1) defines exactly one distribution for every distribution of $\pi(x, n_Y)$.

(4.1) is necessary for any equilibrium. Indeed, equations (11) and (12) are clearly necessary as they follow from the multinomial logit following the model, and they imply (4.1).

There is a single distribution following (4.1) This step proves that, for every distribution of the $g(y)$ and $f(x, n_Y)$, there are several vectors a and b that define a distribution following (4.1); but each of these vectors define the same distribution $\pi(x, y, n_Y)$.

Firstly, let us introduce the notation $\Phi = \exp\frac{\phi}{2}$, and let a be the vector of all the $a(x, n_Y)$, and b be the vector of all the $b(y)$.

It is possible to write the density $g(y)$ as a function of a and b:

$$\begin{aligned} g(y) &= \sum_{x,n} \Phi(x, y, n) \exp((-a(x, n) - b(y))/2) && (22) \\ B_y(a) &:= \exp(-b(y)/2) = \frac{g(y)}{\sum_{x,n} \Phi(x, y, n) \exp(-a(x, n)/2)} && (23) \\ \frac{\partial B_y(a)}{\partial a(x, n)} &= \frac{B_y(a)\pi_a(x, y, n)}{2g(y)} && (24) \end{aligned}$$

where $\pi_a(x, y, n) := \Phi(x, y, n) \exp(-a(x, n)/2)B_y(a)$ is the number of matches of type x, n, y implied by a and the accountability of women in (22). Similarly, $\pi_a(x, n) = \sum_y \pi_a(x, y, n)$ is the number of males of type x, n implied by a.

We search for the vectors $a \in \mathbb{R}^k$ such that $\pi_a(x, n) = f(x, n)$ for every (x, n), and we show that all the solutions lead to the same density.[20]

Firstly, there is always a vector a that solves $\pi_a(x, n) = f(x, n)$ for every (x, n). Indeed, $\pi_a(x, n)$ is a continuous function of a and for every (x, n):

$$\begin{cases} \lim_{a(x,n)\to+\infty} \pi_a(x, n) = 0 \\ \lim_{a(x,n)\to-\infty} \pi_a(x, n) = \sum_y g(y) = 1 \end{cases} \qquad (25)$$

Thus, the generalization of the intermediate values theorem to the multidimensional case, the Poincaré-Miranda theorem, proves there is a solution to the problem. (Technically, the Poincaré-Miranda theorem applies only to bounded sets. However, changing the variable to $a' = tanh^{-1}(a)$ trivially solves this issue.)

[20] k is the number of points on the support of x, n

Secondly, let us study the gradient of $\pi_a(x,n)$. The partial derivatives of π_a are:

$$\frac{\partial \pi_a(x,n)}{\partial a(x,n)} = \frac{1}{2}\sum_y \left(-1 + \frac{\pi_a(x,y,n)}{g(y)}\right)\pi_a(x,y,n) \tag{26}$$

when $x' \neq x$ or $y' \neq y$:

$$\frac{\partial \pi_a(x,n)}{\partial a(x',n')} = \frac{1}{2}\sum_y \frac{\pi_a(x',y,n')}{g(y)}\pi_a(x,y,n) \tag{27}$$

Let $u = (u(x,n))$ be a vector that defines a direction in the space of the vector a. Then:

$$\text{grad}\pi_a(x,n)\cdot u = -\frac{1}{2}\sum_y \pi_a(x,y,n)\left[u(x,n) - \sum_{x',n'} u(x',n')\frac{\pi_a(x',y,n')}{g(y)}\right] \tag{28}$$

Here, $\sum_{x',n'} u(x',n')\frac{\pi_a(x',y,n')}{g(y)}$ is the weighted average of the $u(x',n')$, where the weights follow the distribution of the x', n' conditionnal on y implied by a. Hence, for x_m, n_m such that $u(x_m,n_m)$ is maximal, the sign of (28) is constant. Two cases emerge:

- For every x, n, $u(x,n) = \alpha \in \mathbb{R}$. $\text{grad}f_{x,n}(a)\cdot u = 0$: the densities are unchanged for a variation of a in this direction. The reason is the following: if $a(x,n)$ increase by α for every x,n and $b(y)$ decrease by α for every y, equation (4.1) is unchanged.

- $u(x,n)$ depends on x,n, $u(x_m,n_m) > u(x,n)$ for some x,n, and $\text{grad}f_{x_m,n_m}(a)\cdot u < 0$. For any line of the space following the direction defined by u, there is exactly one point such that $f_{x_m,n_m}(a) = \pi(x_m,n_m)$. So there is at most one point such that $f_{x,n}(a) = \pi(x,n)$ for every (x,n).

So for every line of the space, there is at most single density following equation (4.1), $g(y)$ and $f(x,n)$. There cannot be several densities over $\mathbb{R}^k$ ($\mathbb{R}^k$ is a star domain).